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DREDGED MATERIAL RESEARCH PROGRAM

TECHNICAL REPORT D-78-35

VERTICAL MIGRATION OF BENTHOS IN SIMULATED DREDGED MATERIAL OVERBURDENS

VOL. I: MARINE BENTHOS

by

D. L. Maurer, R. T. Keck, J. C. Tinsman, W. A. Leathem
C. A. Wethe, M. Huntzinger, C. Lord, T. M. Church

University of Delaware
College of Marine Studies
Lewes, Delaware 19958

June 1978
Final Report

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1. The work reported herein was undertaken as Work Unit 1D03 of Task 1D, Effects of Dredging and Disposal on Aquatic Organisms, of the Corps of Engineers' Dredged Material Research Program. Task 1D was a part of the Environmental Impacts and Criteria Development Project (EICDP), which had a general objective of determining on a regional basis the direct and indirect effects on aquatic organisms due to dredging and disposal operations. The study reported on herein was part of a series of research contracts developed to achieve the EICDP general objectives.

2. The specific objective of this research was to determine the effect of simulated dredged material disposal on the vertical migration ability and survival of selected benthic marine invertebrates. Animals were exposed to varied layers of natural sediment in different sizes of plastic cores and larger aquaria. Sediment types ranged from 100 percent sand to 100 percent silt-clay. Sediment analyses included grain size, percent silt-clay, void ratio, and total organic carbon content. Chemical analyses of sediment pore water included dissolved oxygen, pH, dissolved ammonia, dissolved sulfide, and Eh.

3. The results indicate little change in surface water chemistry during the two-week experimental period. However, there were important temporal changes in the concentration of dissolved oxygen, sulfide, and ammonia in the pore water of the sediment. Generally dissolved oxygen decreased while dissolved ammonia and sulfide concentrations increased. The burrowing responses of the organisms were influenced by sediment type, sediment depth, duration of burial, and temperature. Mortalities increased with increased sediment depth and burial time and with increasingly different sediment particle sizes from the preferred habitat of the animals. Many of the species tested revealed a surprising ability to migrate vertically and survive when exposed to relatively thick depths of sediment.

4. The information and data published in this report contribute to a further understanding of the complex nature of sediment, water, and physical/biological interactions and establish a baseline from which to

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develop meaningful evaluations for the selection of an environmentally compatible disposal alternative. It is expected that the methodology employed in this study and the resulting interpretation of the physical/biological interactions will be of significant value to those concerned with CE dredged material permit programs.

JOHN L. CANNON
Colonel, Corps of Engineers
Commander and Director

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This research was conducted to determine the effect of simulated dredged material disposal on the vertical migration ability and survival of benthic invertebrates (*Mercenaria mercenaria*, *Nucula proxima*, *Ilyanassa obsoleta*, *Scoloplos fragilis*, *Nereis succinea*, *Parahaustorius longimerus*, and *Neopanope sayi*).

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void ratio, water content, percent silt-clay, and total organic carbon content varied significantly with time and sediment depth. The concentration of dissolved oxygen in the pore water decreased rapidly throughout the experiment; sulfide and ammonia concentrations in the pore water increased the first week and then remained fairly constant throughout the second week; pH and Eh remained essentially unchanged over the same period. Since the surface water chemistry appeared more conducive to the survival of benthic organisms than the pore water chemistry, the organisms may have needed to reestablish direct or indirect contact with the surface waters via siphons, tubes, burrows, etc., through the dredged material overburden.

One basic pattern of vertical migration or burrowing response occurred when the majority of animals migrated from substratum zero and established an even distribution, normal distribution, normal distribution skewed to either upper or lower sediment layers, bimodal distribution, or polymodal distribution in the overlying sediment. The other pattern occurred when the majority of animals remained in substratum zero or in the bottom-most layers.

Mortalities generally increased with increased sediment depth, with increased burial time, and with overlying sediments whose particle size distribution differed from that of the animals' preferred habitat. Temperature affected mortalities under certain conditions, but percent migration was more responsive than mortality to temperature. In addition, mortality and percent migration were influenced by synergistic effects of experimental variables. Because physiological conditions of animals differ widely from area to area, unqualified extrapolation of these results to other areas and animals with morphology similar to those tested here should be done with caution. However, the morphological and habitat approach was considered a viable means to develop a dependable method for prediction.

Many of the species tested showed a surprising ability to vertically migrate and successfully survive in relatively thick deposits of native and exotic sediments. Assuming worst-case laboratory conditions, vertical migration may be an important factor in the recovery of benthic communities in dredging and dredged material disposal areas.

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SUMMARY

Rationale and General Methodology

This research was conducted to determine the effects of simulated dredged material disposal on the vertical migration ability and survival of common estuarine and marine benthic invertebrates. The species included the bivalves, *Mercenaria mercenaria* and *Nucula proxima*; the mud snail, *Ilyanassa obsoleta*; the polychaete worms, *Scoloplos fragilis* and *Nereis succinea*; the amphipod crustacean, *Parahaustorius longimerus*; and the xanthid mud crab, *Neopanope sayi*. These species were tested in a series of experiments over a two-year period.

During the course of this project, 40 tons of sediment were collected and processed to provide substratum for 481 experiments and 15,174 test animals. One series of experiments were conducted in several different sizes of plastic cores. These experiments ranged from several hours to several days and provided valuable insight as to the boundary conditions of maximum terminal depths of test species and practical lengths of time for given experiments.

Based on the knowledge gained from core experiments, a new series of experiments were designed which used larger test containers (aquaria). Two general types of aquaria experiments were conducted. Aquaria experiments "A" were performed for one-day and eight-day periods under summer water temperatures. These experiments featured two or three different depths of the same sediment type (silt-clay or sand). The effect of winter temperatures was also examined here.

Aquaria experiments "B" were performed for one-, eight-, and fifteen-day periods under summer temperatures. These experiments featured four different sediment types per experiment (100 percent silt-clay, 20 percent silt-clay/80 percent sand, 40 percent silt-clay/60 percent sand, and 100 percent sand).

For all burial experiments, sediment analyses were made of grain size, percent silt-clay, void ratio, water content, consolidation rate, and total organic carbon content. After the first year, measures of

sediment pore water chemistry were made from sediment in aquaria experiments "B." These measures included: dissolved oxygen, pH, dissolved ammonia, dissolved sulfide, and Eh.

Results

Sediments

For 100 percent sand there was no consolidation over the testing period and no significant variation in void ratio with depth or time. For 100 percent silt-clay, there was considerable consolidation during each experiment with significant decreases in void ratio and water content with depth and time. Total organic carbon content did not change significantly with depth or time in either sediment type.

Changes in sediment parameters in mixtures of 20 percent silt-clay/80 percent sand and 40 percent silt-clay/60 percent sand were intermediate. Both sediment types showed no significant change in percent carbon with time. However, there were significant changes in void ratio, water content, and percent carbon with depth for 20 percent silt-clay/80 percent sand. For 40 percent silt-clay/60 percent sand there were significant changes in void ratio and water content with depth and void ratio with time.

Pore water sediment chemistry

The surface water remained essentially chemically constant over time. There was no significant difference in sediment pore water chemistry as a function of sediment composition or depth below the sediment-water interface. However, temporal changes occurred in the sediment pore water chemistry during the two-week experimental period. The concentration of dissolved oxygen decreased rather steadily throughout the experiment. Dissolved sulfide and ammonia concentrations increased during the first week and then remained fairly constant throughout the second week. The pH and Eh data remained essentially unchanged over the same period.

The most striking contrast was seen by comparing surface water data to pore water data. Oxygen values were an order of magnitude lower

in the pore waters than in the surface waters. Ammonia values were over an order of magnitude greater in pore waters than in surface waters. Sulfide values became rather high in the pore waters, while no sulfide was ever detected in the surface waters. In addition, the pH was about 0.7 unit lower in the pore waters and the Eh readings more negative than those in the surface waters. In summary, the surface water environment appeared to be much more conducive to the survival of benthic organisms than the environment which exists within the sediment.

Biota

There were several basic patterns of vertical migration or burrowing response in the burial experiments. (a) The majority of animals migrated from substratum zero and were distributed several ways: (1) evenly distributed throughout the layers; (2) normal distribution with its mode at an intermediate sediment layer; (3) normal distribution skewed to upper layers or to lower layers; (4) a bimodal distribution; (5) a polymodal distribution. (b) The majority of animals remained in substratum zero or in the bottom-most layers.

Burrowing responses (percent migration and mortality) were influenced by sediment type, sediment depth, duration of burial, and temperature. In general, mortalities increased with increased sediment depth, with increased burial time, and as the particle size distribution of the overlying test sediment was made increasingly different from the preferred habitat of the animals. Although there was some association between mortality and temperature, percent migration was relatively more influenced by temperature than mortality. In general, no clear relationship between burrowing activity and sediment pore water chemistry was demonstrated. However, we believe that levels of dissolved oxygen and ammonia obtained in these experiments may have approached concentrations that might have stressed some of the test organisms which were unable to reestablish contact with the surface water within the test period.

Burrowing activity varied depending on the combination of sediment type, sediment load, duration of burial, and temperature. The complex synergistic environmental factors regulating the physiological condition of animals differ widely from area to area and over time. Because of

this, we recommend caution in unqualifiedly using analogous morphological species and habitats to make other than general predictions on the effect of dredged material disposal. This may become possible as additional studies with many taxa show general association between certain morphological characteristics and burrowing behavior. At the same time, we think that the morphological and habitat approach should be continued, expanded, and refined as a means to develop a dependable method for prediction of physical impacts of sediment burial on benthic organisms.

In conclusion, many of the species tested in these experiments showed a surprising ability to vertically migrate and successfully survive under laboratory conditions in relatively thick depths of sediments with particle size distribution both similar to and different from their preferred sediment habitat. Assuming that in most cases laboratory experiments of this type represent worst-case conditions compared to field conditions, then vertical migration may be an important factor in the recovery of benthic communities in dredged material disposal areas.

PREFACE

This report describes work performed for the Environmental Laboratory of the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi, under Contract No. DACW 39-74-R-0019 dated 21 January 1974, entitled "Vertical Migration of Marine Benthos in Dredged Material Deposits." The work was performed as Work Unit 1D03, Task 1D, of the Dredged Material Research Program.

The work described in this report was performed by the University of Delaware, College of Marine Studies, Lewes, Delaware.

Principal Investigators were Dr. Don Maurer and Mr. Richard T. Keck, College of Marine Studies. Messrs. Jeff Tinsman, Wayne Leathem, and Robert Heess assisted in the field collection and biological laboratory experimentation. Mr. Christian A. Wethe, assisted by Ms. Margie Huntzinger, performed the physical sediment analysis. Dr. Thomas M. Church directed the sediment chemistry work performed by Mr. Charles J. Lord and assisted by Ms. Jane Hislop.

The contract was monitored by Dr. Robert Engler, Chief, Environmental Impacts and Criteria Development Project, and Contract Managers, Mr. Rex Bingham, Ms. Susan Palmer, Dr. Russell Plumb, and Dr. Richard Peddicord. Dr. Peddicord was extremely cooperative in helping us to prepare the final version of this report.

The Directors of WES during the study were COL G. H. Hilt, CE, and COL J. L. Cannon, CE. Technical Director was Mr. F. R. Brown. Chief of the Environmental Laboratory was Dr. John Harrison.

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
microns	0.001	millimetres
inches	25.4	millimetres
feet	0.3048	metres
cubic yards	0.76455	cubic metres
gallons (U. S. liquid)	0.00379	cubic metres
tons (short)	907.1847	kilograms

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VERTICAL MIGRATION OF BENTHOS IN SIMULATED DREDGED MATERIAL OVERBURDENS

VOL. I: MARINE BENTHOS

PART I: INTRODUCTION

1. In aquatic systems one of the major forces influencing the environment is the dredging industry (Hann and Hutton 1970). Construction of offshore power plants, multipurpose deepwater ports, and mineral extraction facilities, together with routine maintenance of waterways, is expected to increase the need for dredging in coastal areas (Rounsefell 1972, Watling 1975). Currently, approximately 400 million yd^3* are dredged annually to maintain navigational channels (Lee 1976). Federal pollution-control agencies have become increasingly concerned about the environmental impact of dredged material disposal. As a result, the U. S. Army Corps of Engineers initiated a comprehensive dredged material research program to ascertain environmental impact and develop new or improved disposal practices (Boyd et al. 1972).

2. The purpose of this report is to present data on vertical migration of marine benthic organisms through simulated dredged material. The primary objectives of this research include: (1) determination of the ability of estuarine benthos to vertically migrate in sediments considered to be natural (that is, similar in particle size distribution to preferred natural habitat type) and exotic dredged material (that is, a sediment not normally encountered); and (2) determination of survival of benthos when exposed to particular amounts of dredged material.

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 7.

PART II: HISTORICAL BACKGROUND AND LITERATURE REVIEW

3. The majority of the existing literature on the burial of benthic organisms concerns commercially important bivalve molluscs (Glude 1954, Dunnington 1968). Information concerning other macrobenthos is less frequent and is often in conflict as to the organisms' ability to migrate vertically through sediment overburdens. However, there seems to be little disagreement in regard to the destruction of sessile, epifaunal benthic invertebrates such as oysters, mussels, and barnacles by sediment deposition (Wilson 1950, Hopkins 1973, May 1973, Rose 1973, Maurer et al. 1974, Slotta and Williamson 1974). At the same time, considerable uncertainty and disagreement have been reported concerning environmental impacts of dredged material, effects of turbidity, nutrient release, chemical contamination, and oxygen demand on infaunal invertebrates (Sherk 1971, Myers 1972, Oliver and Slattery 1973, Peddicord et al. 1975).

4. To date, much information on the burrowing ability of invertebrates and their escape response from sediments has come from paleoecology (Armstrong 1965; Kranz 1972, 1974; Schafer, 1962, 1972). Kranz (1972) conducted a study on the burrowing ability of 30 species of pelecypods. The following description is a summary of his conclusions. Life habitats were important in determining ability to escape burial. Epifaunal suspensions feeders, borers, and adult deep-burrowing siphonate suspension feeders generally were unable to escape more than a 1-cm overburden. Infaunal non-siphonate suspension feeders were able to escape 5 cm of their native sediment, but normally less than 10 cm. Shallow-burrowing siphonate suspension feeders and young, deep-burrowing siphonate suspension feeders escaped between 10 and 50 cm of their native sediment. Mucous tube feeders and labial palp deposit feeders were most susceptible to burial. Exotic sediments (differing greatly in particle size distribution from the preferred substrate) were often lethal or caused a reduction in the organisms' ability to burrow. In general, larger bivalves of each species showed statistically higher escape percentages per depth of burial than smaller ones. This pattern

did not hold for deep-burrowing siphonate suspension feeders and mucous tube feeders. There was no correlation between normal living depth and exhuming ability. Temperature, salinity, and oxygen concentrations were negligible in limiting bivalve escape abilities, except at the extreme end of their tolerance ranges.

5. Stanley (1970) developed a number of relationships between morphology (shell length, thickness, shape, ornamentation, and interior volume) and burial of molluscs. Most rapid burrowers were crudely disc-like, blade-like, or cylindrical, rather than spheroidal. Elongate and pointed shell anteriors often coincided with rapid burrowing habits. Strong ornamentation and thick valves were characteristics of shallow, slow burrowers. In contrast to Kranz (1972), Stanley found that deep-burrowing infauna were least susceptible to burial problems, with shallow-burrowing infauna falling between deep burrowers and the epifauna.

6. In addition, both Kranz and Stanley indicated that bivalve foot morphology is highly correlated with escape ability. Bivalves with a reduced foot or one modified for byssal attachment had virtually no burrowing ability. Bivalves with a large cylindrical muscular foot, which occupies most of the interior volume of the shell, were successful burrowers. Other foot morphologies offered a variety of escape abilities. There was some evidence to indicate that those bivalves which used less water in burrowing were better escape burrowers than those which used more.

7. The dynamics of the burrowing of bivalves have been studied, particularly by British workers, who have provided important information on burrowing ability (Trueman et al. 1966, Trueman 1968, Trueman and Ansell 1969, Ansell and Trueman 1973). Of particular physiological importance was the study by Ansell and Trueman (1973), which determined the energy cost of migration for the small bivalve Donax. The authors found that maintenance of position between migratory movements requires expenditure of more energy than does emergence and reburial during migration.

8. Saila et al. (1972) stated that it was possible to predict

survival and migrating ability based on morphology and behavior of the animal under natural conditions. Burial experiments conducted with up to 21 cm of dredged material produced the following results. The polychaete, Nephtys incisa, reached the surface from all depths in less than 24 hours. Streblospio benedicti, a small tube-dwelling polychaete, was able to reach the surface of only 6 cm of sediment. Mulinia lateralis, a small filter-feeding bivalve, reached the surface from all depths, but many individuals took over 24 hours.

9. Experiments conducted by Hale (1972) show that Arctica islandica can reach the surface of 4-5 cm of dredged material (fine mud) and as much as 14 cm of sand. Clams buried under 8-17 cm of dredged material did not migrate upward, but established "blow holes" to the surface. Oliver and Slattery (1973) observed similar behavior with the large bivalve, Tresus nuttallii, which established blow holes to the surface through approximately 15 cm of dredged material. They reported that polychaetes were least affected by burial experiments conducted in the field with a subtidal community. Survival was highest among active burrowers that were common in deeper sediment strata. Surface-dwelling crustaceans and molluscs experienced 100 percent mortalities when buried. When compared with a nearby reference area, the number of individuals was temporarily reduced 50 percent by the sediment deposition (Oliver and Slattery 1973).

10. Glude (1954) conducted field burial experiments with Mya arenaria covered by up to 22 cm of a variety of sediments. Survival varied inversely with depth of burial and directly with size of bivalves. Survival was lowest in silt, highest in silty sand, and higher in winter than summer. In laboratory experiments, Pfitzenmeyer and Drobeck (1967) showed that rates of burrowing by M. arenaria were directly affected by temperature. However, they also stated that these rates were specific to certain ranges of temperature and species of bivalves. Schafer (1972) reported that M. arenaria could escape from 10 cm of sand in two to ten hours.

11. Shulenberger (1970) concluded that Gemma gemma, a small bivalve, could exhume itself from 23 cm of sand and 5.7 cm of silt.

Survival for up to six days prior to exhumation was possible under a variety of conditions.

12. Maurer (1967) found that Transennella tantilla, a small bivalve similar to G. gemma, was able to cope with highly turbid conditions and moderate overburdens of clay. In contrast, Gallucci and Kawaratani (1975) found high mortalities when Transennella tantilla juveniles were buried in the field. The authors concluded that similar mortalities would be observed for clams such as M. mercenaria.

13. There are several studies with soft-bodied organisms which bear mentioning. Polychaetes with distinct heads and well-developed acicula, parapodia, and setae are normally considered excellent burrowers (Pettibone 1963). Polychaetes which build tubes and remain near the surface would be expected to be poor burrowers compared with polychaetes which show strong infaunal tendencies. However, Myers (1972) and Oliver and Slattery (1973) found that the onuphid polychaetes, Diopatra cuprea and Nothria elegans, respectively, were capable of exhuming themselves from 30 cm of sediment.

14. Bousfield (1970) offered generalizations on morphology and burrowing ability in amphipods. Within the subfamily Haustoriinae, the most efficient adaptation of body form for a sand-burrowing mode of life has occurred. These genera possess a truncated, fusiform body with ventral "tunnel" formed by large coxal plates and expanded peraeon segments. Strongly modified pleopods are adapted for rapid burrowing. Other families of sand-burrowing amphipods may exhibit some subset of these morphological features, but not to the extent of the Haustoriinae.

15. Peddicord et al. (1975) noted that Crangon nigricauda started to migrate immediately as bentonite clay was slurried into the experimental tanks. The shrimp swam continuously until the bentonite had compacted sufficiently to provide support. The isopod, Synidotea laticauda, behaved similarly to the shrimp. Twenty percent mortality occurred when 6 to 8 cm of bentonite slurry were added.

16. McCall's (1977) research with colonization experiments of infaunal benthos is representative of the new thrust in benthic ecology. He collected high numbers of infaunal benthos ten days after he had

placed defaunated mud in Long Island Sound. Colonization sequences can be initiated by storms, increased sedimentation, and destabilization of the substratum. Results of his study indicated that there is a characteristic sequence of species that follows a disturbance of the bottom. This sequence may be determined by means of in situ colonization experiments. McCall proposed that this methodology with some modification may find immediate application in predicting the sequence and rate of recovery of the bottom fauna from dredging and disposal of dredged material.

PART III: EXPERIMENTAL METHODS

Rationale for Experimental Procedures

17. The primary biological parameters assessed were distances of vertical migration, the number of migrating animals, and survival of benthic organisms when covered with native and exotic simulated dredged material. These results will hopefully provide data useful to managers in planning to minimize possible harmful effects of open water dredged material disposal. For example, baseline benthic surveys of the fauna would be conducted to determine dominant forms. Then data obtained from this research might be applied to provide guidelines on the amount and type of material disposed in a given area to obtain an estimate of the percent of dominant benthic organisms which might survive burial.

18. The experiments were performed in the laboratory to reduce the effect of synergistic factors normally encountered in the field (salinity, turbidity, temperatures, and dredged material deposition). Moreover, problems in estimating the density of organisms in the field make it extremely difficult to accurately assess mortalities caused by the dredged material overburden. Escape and contamination of samples by small benthic organisms in the laboratory are still difficult problems, but in the field these problems are magnified.

19. Experiments were initially conducted in plastic cores to determine the general boundary conditions for the experimental design. These experiments were intended to provide results over a wide range of experimental conditions to obtain some impression of the relative burrowing ability of a variety of organisms. The test organisms were covered with native and exotic sediment. The effect of temperature was also studied. Physical properties of sediment were monitored to ensure that reasonably consistent sediment types were used in the experiments. Based on the preliminary core experiments, more definitive experiments were conducted in aquaria.

Biological Methods

Test species

20. Selection of test species was based on the criteria of geographic range, ecological dominance, accessibility, ease of laboratory conditioning, and burrowing criteria discussed in the literature survey. Species with relatively broad geographic distributions were selected to increase the probability of viable information transfer from one area to another. However, apparently slight differences in genetic strain (Stauber 1950), physiology (Loosanoff and Nomejko 1951), and ecological habitat must be accounted for when attempting to extrapolate data between species and geographical area. Ecological dominance was used as a criterion, because the organisms present in highest density or biomass with widest distribution are more likely to occur in areas where dredging and dredged material disposal activities are taking place. Based on life history and natural sediment preferences, species were selected that were commonly found in either a sand or mud substratum. Thus sand would be considered an exotic dredged material for mud-dwelling organisms, and conversely mud was an exotic dredged material for a sand-dwelling species. The last criterion cited above, burrowing ability, is specific for this research. This study has purposely avoided organisms that research has indicated are clearly vulnerable to burial effects, e.g., sessile, stalked, or encrusting organisms such as oysters, hydroids, barnacles, tunicates, and ectoprocts. Mobile invertebrates such as shrimps, portunid crabs, and scallops were not considered because of their ability to avoid dredging and disposal operations. Organisms capable of burrowing were selected for the burial studies. An attempt was made to include representative species which meet the above criteria from as many of the major taxonomic groups as possible.

21. The species listed in Table 1 were selected for testing. During the second year of the project *Mercenaria mercenaria*, *Scoloplos fragilis*, *Nereis succinea*, and *Parahaustorius longimerus* were studied in greater detail than the other three species.

Table 1

Species Selection List for Migrating Benthos Study

Group	Species	Substratum Preference	Source*
Pelecypoda	Mercenaria mercenaria	Sand or mud	UDMF
	Nucula proxima	Mud	DB, Anchorage Area
Gastropoda	Ilyanassa obsoleta	Mud	CH
Polychaeta	Scoloplos fragilis	Sand	CH
	Nereis succinea	Mud or Sand	DB
Amphipoda	Parahaustorius longimerus	Sand	HC
Decapoda	Neopanope sayi	Mud and shell	DB

* UDMF = University of Delaware mariculture facility, DB = Delaware Bay, CH = Cape Henlopen Tide Flat, HC = Hen and Chickens Shoal.

Test sediments

22. Sediments used in the burial experiments for substratum and simulated dredged materials were collected several ways. Coarse sediment from the Cape Henlopen, Delaware, tide flat was used extensively as a sand substratum. It was collected by shovel and returned to the laboratory where it was sieved through a 1-mm-mesh screen to remove the macroscopic benthic invertebrates. This sand was then air-dried to eliminate eggs, larvae, and juveniles of invertebrates which might have passed through the screen.

23. A fine, clean (<1% silt-clay) well-sorted sand was collected from Hen and Chickens Shoal off Delaware for use as simulated sand dredged material. This was taken from 2.7-5.4 m of water with a Van Veen grab and immediately sieved through a 1.0-mm screen to remove invertebrates. This sediment was also air-dried to eliminate eggs, larvae, and juveniles.

24. Fine sand sediment was collected just north of Roosevelt Inlet, Delaware, with a Van Veen grab. This was placed in large containers and returned to the laboratory where it was sieved through a 1-mm screen into a large concrete holding tank. Since air-drying adversely affected the texture of this sediment, it was stored wet. This sediment was

inundated periodically and drained to preclude recruitment of benthic organisms in the material. In addition, sediment was collected from the laboratory holding tanks and used for some early core experiments. Fine silt-clay was collected by Van Veen grab from the University harbor near Roosevelt Inlet. These sediments were sieved and stored as described above and were primarily used in the aquaria experiments. The aquaria experiments involved two general sediment designs. One set of experiments used several different depths of either sand or silt-clay. The second set of experiments used combinations of approximately 100 percent sand, 20 percent silt-clay/80 percent sand, 40 percent silt-clay/60 percent sand, and 100 percent silt-clay. In view of the difficulty in preparing the specified ratio of silt-clay and sand, the variability was surprisingly low.

Collection of test species

25. The collection of experimental animals varied with the species. The hard clams, *Mercenaria mercenaria*, were laboratory-reared juveniles obtained from the University of Delaware's mariculture facility. They ranged in size from 1.5 to 2.0 cm (anterior-posterior length). The polychaete, *Nereis succinea*, was collected by hand from the muddy intertidal riverbanks of the Broadkill River, adjacent to the laboratory. This species ranged in size from 5.0 to 12.0 cm (anterior-posterior length). The polychaete, *Scoloplos fragilis*, was retained on the sieve screens in the collection of Cape Henlopen sand. This polychaete ranged in size from 2.5 to 5.0 cm (anterior-posterior length). The amphipod, *Parahaustorius longimerus*, was retained in a similar manner while sieving sand from Hen and Chickens Shoal. This species ranged in size from 0.5 to 1.0 cm (anterior-posterior length). The bivalve, *Nucula proxima*, was collected with a Van Veen grab at several stations in the anchorage area off Big Stone Beach, Delaware. This bivalve ranged in size from 0.8 to 1.3 cm (anterior-posterior length). The gastropod, *Ilyanassa obsoleta*, and the xanthid crab, *Neopanope sayi*, were collected by hand--the former from the Cape Henlopen tide flats, the latter from strings suspended from an oyster culture raft in the Broadkill River. For one set of experiments, the snails were categorized as small, medium, and

large. Small ranged from 1.0 to 1.5 cm, medium from 1.5 to 2.5 cm, and large from 2.5 to 3.5 cm (length from nuclear whorls to tip of canal). For most experiments, medium-sized snails were used. The size of the crabs ranged from 2.0 to 2.5 cm (width of carapace).

Temperature and
salinity for experiments

26. Water for these experiments was drawn from the Broadkill River, adjacent to the laboratory and near Roosevelt Inlet. The water was first passed through a sand and gravel filter and then through a 5μ filter bag prior to use. The system was designed to remove the heavy silt load which the river carries to Delaware Bay as well as most meroplankton and holoplankton. Water temperature was maintained with a heat exchanger and a refrigeration unit. In aquaria experiments, the mean for summer experiments was 19.4°C. The temperature range was ±2°C for most experiments. For the winter or cold-water experiments, temperatures ranged between 5-10°C. The salinity range through the experiments was 20-26 ‰.

Maintenance and
acclimatization of test species

27. After collection, the infaunal species, *Nucula proxima*, *Mercenaria mercenaria*, *Scoloplos fragilis*, and *Parahaustorius longimerus*, were placed in shallow glass pans of their native sediment. These specimens were held for 7-14 days to allow the animals to acclimatize to the salinity and temperature regime of the laboratory situation. The more active polychaete, *Nereis succinea*, was held in 55-gallon aquaria. The epifaunal gastropod, *Ilyanassa obsoleta*, and the xanthid crab, *Neopanope sayi*, were maintained in a large fiberglass tank which held the five experimental aquaria.

28. The amphipod, *Parahaustorius longimerus*, presented problems in identification, the most important of which were:

a. Size--This species required microscopic examination of each individual.

b. Activity--This species tended toward hyperactivity compared with others which made close observation difficult and time consuming.

c. Closely related species required similar detailed treatment for differentation.

Collection sites were chosen based on seasonal faunal surveys which had shown that 90 percent of the individuals from this family were of this one species. It is highly probably that 90 percent of the individuals tested were *P. longimerus*. During the aquaria experiments, the time and expertise became available to make identification to the species level possible at the onset and termination of all experiments.

Equipment and Experimental Protocol

29. Experimental equipment and procedures evolved during the course of the study. During the preliminary stages, all invertebrates listed in Table 1 were tested to determine survival time, capability of vertical migration, and terminal depths achieved in sand and mud. As the project progressed, four species were tested at one depth of four simulated dredged material types nominally termed 100 percent sand, 20 percent silt-clay/80 percent sand, 40 percent silt-clay/60 percent sand, and 100 percent silt-clay. A representative experiment is depicted in Figure 1 showing the equipment used in the various types of experimental designs; (1) the 5-cm core, (2) the 10-cm core, and (3) the 55-gallon aquaria.

30. Experiments were initially run in 5-cm-diameter plexiglass tubes set up within 55-gallon aquaria. Test animals were placed in 16 cm of substratum (native sediment) and allowed to enter the sediment for 24 hours. A piece of 1-mm-mesh screening retained a counted number of acclimatized organisms within each core. Extensions to the cores, held in place by collars, allowed various depths of simulated dredged material to be added in a slurry form. Depths ranging from 2 to 32 cm were tested. Three replicates of each dredged material (DM) depth and a control core, with no dredged material added, were generally sampled during each experimental period. Samples ranged from two hours to several days. When sampled, the sediment was extruded in 1-cm increments and sieved. Live and dead experimental animals in each layer

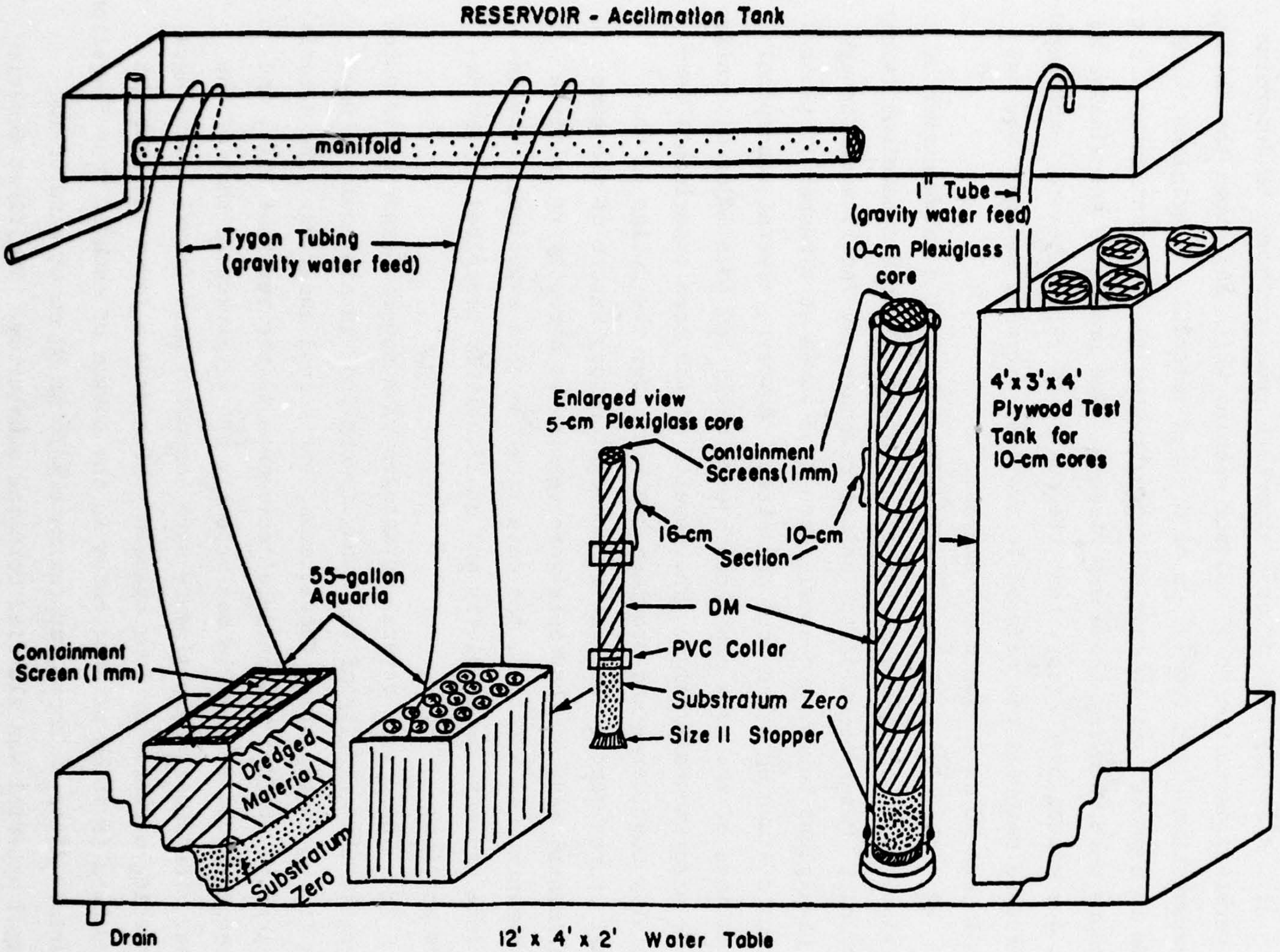

Figure 1. Schematic diagram of experiment chambers and water used for Migrating Benthos study

were recorded. Live animals were placed in trays with native fresh sediment to determine their ability to reburrow rapidly.

31. A second type of core experiment was performed to determine the terminal depth (up to 85 cm) for species which had shown the ability to exhume themselves from 32 cm of dredged material. Plexiglass tubes 10 cm in diameter set in specially constructed plywood containers 1.5 m in depth were used for those experiments. The procedure was similar to that described above except that the number of replicates for each depth of dredged material was reduced to two, and extruded sediment was cut into layers 10 cm in depth and sieved.

32. The core experiments allowed sampling of a known number of individuals per core, and depths of the organisms were determined fairly precisely. Observation of the animal response was facilitated through the plexiglass tubes, and samples could be taken at a number of times without disturbing other test organisms. However, several conceptual limitations of the core experiments eventually led to a major alteration of the experimental design. The results of the core experiments were carefully considered and provided the basis for the design of the aquaria experiments. Because of the exploratory nature of the core experiments, many of the tests were terminated abruptly to initiate refinements. As a result, the data from the core experiments are incomplete and have been briefly and qualitatively described in the results section.

33. There were several advantages with aquaria experiments which comprised the majority of the study. More individuals could be used than in the cores, which facilitated statistical analyses. The aquaria did less to channel the animals' movements to the vertical axis, and the edge effect of aquaria was probably not as marked as that of the cores. The aquaria experiments were conducted with faunal assemblages consisting of three or four species, which were allowed to establish themselves in 16 cm of substratum in the bottom of each of four 55-gallon aquaria. After 24 hours, approximately 16 or 32 cm of sand or mud dredged material was slurried onto the substratum. The first aquaria experiments, termed "A" experiments, were 1 day or 8 days in duration.

Later aquaria experiments, termed "B" experiments were 1, 8, or 15 days long.

34. When sampling, dredged material was generally removed in 4-cm increments. After sieving through a 1-mm screen, the number of living and dead animals in each layer were recorded. Animals recovered alive were held in fresh native sediment and observed for 24 hours to assess whether there was any further mortality or inability to assume a natural position in the sediment. Healthy individuals were placed in the water system to be reconditioned for possible further use. Sand contaminated by mud was discarded and uncontaminated sediments were redried and recycled.

Sediment Analysis

35. Sediment samples were collected from the experimental aquaria with a 7-cm-diameter plug corer for determination of bulk density, void ratio, and water content. In addition to the plug core sample, a 10-g sample for total organic carbon measurements and a 100-g sample for determination of grain size and other physical properties were removed from each sampling level.

36. Sample volume and the wet weight of the sample were determined. After drying at 105°C, the sample dry weight was determined and the bulk density and water content calculated. After the specific gravity was measured, the void ratio was calculated.

37. The grain-size analysis of sediments followed procedures described by Folk (1968). The size distribution curves were characterized by the graphic mean, graphic standard deviation, and graphic skewness.

38. Specific gravity was determined with the aid of a Beckman Model 930 Air Comparison Pycnometer from 10-g sediment sample.

39. The total organic carbon of each sediment sample was measured using a Model 185B Hewlett Packard Carbon, Hydrogen, Nitrogen Analyzer (CHN). Samples were treated with hydrochloric acid to remove the carbonates, dried in a desiccator, ground to a fine powder, and run in triplicate.

Chemical Methods

40. During the aquaria experiments for summer water temperatures, sediment pore water chemistry was studied in the experimental chambers to determine if migration could be associated with chemical properties or if toxic levels of various compounds such as sulfide and ammonia occurred within the sediment.

41. In situ water extraction units were placed in an aquarium containing each of the four particle size classes of simulated dredged material tested. The in situ water extraction unit consists of a fritted cell upon which 0.4μ membrane filters have been sealed. The complete unit contains four fritted cells held 10 cm apart in a vertical direction by a PVC framework. Each cell is connected via a length of tygon tubing to the sediment-water interface where the open end of the tube is then sealed off with a rubber septum. Syringes equipped with stainless steel needles are used to create the mild suction which is needed to withdraw the filtered pore water samples from the various depths (i.e 2, 12, 22, and 32 cm) below the sediment-water interface.

42. As an independent check on the validity of such a sampling system, an intercalibration was performed using the standard coring and squeezing method. The results obtained by mechanically squeezing the pore waters from a sediment core sample showed good agreement (within experimental error) with the in situ extraction method. The in situ method was therefore used throughout the course of the project.

43. Pore water samples were withdrawn from the in situ unit at 1 day, 1 week, and 2 weeks of each experiment and analyzed for dissolved oxygen (O_2), pH, dissolved ammonia (NH_3), and dissolved sulfide (H_2S). This provided time-sequence monitoring of the chemical changes which occurred within the pore waters of the dredged material. All analyses were initiated within two minutes of sample collection.

Dissolved oxygen

44. Oxygen samples were obtained from the in situ extraction unit using a 20-ml syringe fitted with a 21-gage stainless steel needle, taking care not to entrap air bubbles inside the syringe. The sample

was injected through a rubber septum into a sealed cell which housed a Yellow Springs Instrument oxygen probe. The probe was standardized with oxygen-saturated water of known salinity and temperature. Stirring of the solutions was accomplished by using a teflon-coated magnetic stir bar.

pH

45. Water samples for pH measurements were obtained from the in situ extraction unit using 10-ml syringes fitted with 21-gage stainless steel needles. The pH measurements were made with a Corning semi-micro combination electrode. This electrode was fitted into a closed equilibration cell and placed in a water bath thermostated at 25°C. The closed cell system was employed to prevent degassing of the sample. The loss of CO_2 or H_2S due to degassing results in high pH values. The pH electrode was standardized using certified buffer solutions according to the method described by Zirino (1975).

Dissolved ammonia

46. Water samples for dissolved ammonia analysis were obtained using 20-ml syringes in a manner similar to that described above for dissolved oxygen (DO) and pH samples. During the course of the work, two methods were employed in the ammonia analyses. The first of these was a standard additions technique using an Orion ammonia electrode. The second was a colorimetric technique described by Solorzano (1969). Both techniques yielded comparable results; however, the colorimetric technique proved to be more practical for the routine analysis of samples. The only modification of the Solorzano method used in this work was the reduction of sample and reagent volumes to one-tenth those recommended for seawater analysis.

Dissolved sulfide

47. Water samples for dissolved sulfide analysis were obtained from the in situ extraction unit, taking care not to entrap air bubbles inside the syringe. The technique employed in the sulfide analyses was the colorimetric methylene blue method described by Cline (1969). The sample was transferred hermetically from the collection syringe into another syringe which contained the colorimetric reagent.

Eh

48. Eh measurements were performed by measuring the potential between a platinum wire electrode and a saturated Calomel reference electrode. The platinum wire was sealed into the tip of a 50-cm length of 1/4-in.-OD glass tubing. This platinum wire probe was then inserted into the sediment to various depths while the reference electrode remained in the circulating surface water of the aquarium.

Data Analysis Procedures

Sediment

49. An analysis of variance (ANOVA) was used to evaluate the influence of depth and time on void ratio, water content, and percent carbon for experiments conducted in the aquaria. Computations follow those recommended by Sokal and Rohlf (1969).

Chemical

50. Table 2 is a statistical evaluation of the analytical methods

Table 2

Statistical Data on Chemical Analytical Methods

Analysis	Precision (1σ)	Detection Limit (ppm)
Dissolved oxygen, O_2	10%	0.096
Total dissolved ammonia, NH_3	10%	0.003
Total dissolved sulfide, H_2S	20%	0.102
pH	2%	--
Eh	20 mV	--

used in this work. The values included in the precision column represent the average precision of replicate samples which were drawn separately from the in situ extraction unit and analyzed. The precision values given are equivalent to one standard deviation ($\pm 1\sigma$). The detection limits listed in the table signify the lowest concentration levels which

can be reliably measured (95 percent confidence) in the pore waters.

Biology

51. Based on pooled replicates, the number, the percent of the total, and the cumulative percent of live and dead animals in each sediment layer and substratum zero at every observation time were tabulated for aquaria experiments "A" and "B." The number of animals that migrated from substratum zero, the percent mortality, and the percent of animals from a given layer were obtained from these tables.

52. Counts of mortality were affected by rapid decomposition of dead amphipods and polychaetes and inadvertent escapes and inclusions. The number of animals placed into each aquarium was first compared to the number of actual live animals found, then the number of dead animals observed was added to those considered missing. This figure was used to calculate mortalities. Counting missing individuals as dead will tend to bias results here. However, if the artifacts of laboratory conditions impose a worst-case situation, than we believe that conditions in the field would tend to be less harmful.

PART IV: DISCUSSION OF PRELIMINARY RESULTS

53. Substratum zero sediment from three sources was employed for the core experiments. The fine-grained material was a very poorly sorted clayey silt. The two coarse-grained sediments were a well-sorted coarse to medium sand and a very well-sorted fine sand.

54. The coarse-grained dredged material was a very well-sorted fine sand. This is the same sand employed in the aquaria experiments. No significant consolidation of this sediment was observed. The fine-grained dredged material was a poorly sorted sandy silt. Consolidation of this material, similar to that which occurred with the muds in the tanks, was noted.

Chemical

55. Chemical data generated in this work can be found in Appendix A (Tables A1-A5). Each table contains three sets of data from three replicate experiments. The depth intervals found at the extreme right-hand side of each table represent the depth below the sediment-water interface from which the pore water sample was taken. The 0-cm depth corresponds to the water circulated over the sediment surface in the aquarium.

56. Ammonia and sulfide data represent the total concentrations of these parameters in the pore waters. The actual speciation of ammonia into the NH_3 and NH_4^+ forms and sulfide into the H_2S, HS^-, and S^{2-} forms is controlled by the pH of the system. It is possible, therefore, to calculate the distribution of total ammonia and total sulfide among their various forms as a function of pH. The amount of nonionic ammonia and sulfide (i.e. NH_3 and H_2S), which poses the greatest threat to the survival of benthic organisms, can be calculated through the use of the following two equations:

57. For the percentage of the total ammonia concentration which is present as NH_3:

$$NH_3\% = (10^{-7.25} \times 10^{pH}) \div [1 + (10^{-9.25} \times 10^{pH})]$$

58. For the percentage of the total sulfide concentration which is present as H_2S (valid for pH <9):

$$H_2S\% = (10^{8.67} \times 1^{-pH}) \div [1 + (10^{6.67} \times 10^{-pH})]$$

59. Within a factor of two, there were no significant differences among the four sediment mixtures based on their pore water chemistry (Tables A1-A5). This indicates that, at least for short-time scale experiments (i.e. two weeks), the sediment mixtures used in this work develop very similar chemical environments within their interstitial waters. Therefore, any chemical stimuli which were created by low dissolved oxygen, high dissolved ammonia, and dissolved sulfide were of comparable magnitude in each of the four sediment systems studied. This means that any systematic variations in the biological response to the different sediment groups cannot be correlated with chemical differences found in the pore waters.

60. The data in Appendix A also do not demonstrate any significant vertical gradients in chemical concentrations in the pore water. In relatively undisturbed marine and estuarine sediments, the pore water depth profiles possess definite vertical gradients which can often be approximately described in terms of steady-state processes (Berner 1971). The fact that the sediments examined in this work have such variable pore water profiles is not surprising since two weeks is too short a time span to establish steady-state conditions within a sediment which had been homogenized at the start of the experiment. Another process which tends to obliterate vertical gradients and homogenize the sediment is bioturbation. In these experiments, there was always a certain amount of sediment disruption due to the movements of organisms. However, this effect was probably of less importance than the initial homogenization process in its effect on pore water profiles.

61. Since there was no significant difference in the chemical environment within the sediments, the data were averaged over depth and sediment type to yield spacially averaged data (Table 3) in order to examine the temporal variations in pore water chemistry. In Table 3,

Table 3

Chemical Parameters Averaged by Replicate Experiments

(Mean $\pm$ One Standard Deviation)

Parameter	Surface Water			Pore Water		
	Day 1	1 Week	2 Weeks	Day 1	1 Week	2 Weeks
Oxygen (mg/ℓ)	5.86 ($\pm$1.08)	5.95 ($\pm$1.02)	5.95 ($\pm$1.03)	0.86 ($\pm$0.64)	0.16 ($\pm$0.23)	0.04 ($\pm$0.10)
pH	7.73 ($\pm$0.17)	7.77 ($\pm$0.16)	7.80 ($\pm$0.07)	7.00 ($\pm$0.23)	7.09 ($\pm$0.22)	7.10 ($\pm$0.20)
Total ammonia (mg/ℓ)	0.51 ($\pm$0.73)	0.18 ($\pm$0.13)	0.25 ($\pm$0.14)	6.12 ($\pm$4.08)	12.24 ($\pm$8.73)	13.65 ($\pm$8.50)
Total sulfide (mg/ℓ)	0	0	0	0	0.87 ($\pm$1.93)	0.85 ($\pm$1.84)
Eh (mV)	-38 ($\pm$34)	-24 ($\pm$38)	-26 ($\pm$31)	-268 ($\pm$41)	-251 ($\pm$48)	-260 ($\pm$31)

data are categorized as *surface water or pore water. The pore water* values were averaged over three replicate experiments, four sediment mixtures, and four depths. The surface water values were averaged over three replicate experiments and four sediment mixtures.

62. The surface water remained essentially chemically constant over time (Table 3). This was expected since the surface water was continually renewed during the course of the experiments. Any variations in the surface water values most likely resulted from chemical changes that had occurred in the water pumped from the Broadkill River.

63. However, temporal changes occurred in the sediment pore water chemistry during the two-week experimental period (Table 3). The concentration of dissolved oxygen decreased rather steadily throughout the experiment. This decrease was probably due to a combination of inorganic oxidation reactions and respiration. Dissolved total sulfide and total ammonia concentrations increased during the first week and then remained fairly constant throughout the second week. The probable explanation for the increases in ammonia and sulfide is the remineralization of organic matter by bacteria within the sediment. This

bacterially mediated decomposition can release various metabolic products including ammonia and sulfide into the pore waters. Richards (1965) discussed such stoichiometric oxidation models in detail for organic matter of a given C:N:P ratio in the open ocean and Sholkovitz (1973) applied similar arguments to the pore waters of marine sediments.

pH and Eh

64. The pH and Eh data, however, remained essentially unchanged over the two-week period (Table 3). This was not surprising since the pore waters are generally well-buffered systems due to the increased levels of weak acid buffer components (H_2CO_3 and H_2S systems) which tend to stabilize the pH of the environment. The Eh data collected throughout this work were quite unstable and apparently insensitive to changes in pore water chemistry. The measurement of Eh using a platinum probe was often hampered by poisoning of the electrode which led to extremely variable readings.

General

65. There were a few instances where dissolved oxygen and dissolved sulfide were present simultaneously in rather low concentrations (Tables Al and A4). This may at first seem contradictory; however, several studies (Cline and Richards 1969, Sorokin 1970, Chen and Morris 1972) have shown that oxygen and sulfide can coexist in solution for as long as 30 days. The reason for this phenomenon is that the kinetics of the oxidation process are slow enough to allow a metastable condition to exist between oxygen and sulfide. There is also a finite possibility that the oxygen samples became inadvertently contaminated during the extraction and analytical procedure, which could therefore account for the oxygen present.

66. The most striking constrast can be seen by comparing the surface water data to the pore water data in Table 4. In Table 4, the pore water data were averaged over three replicate experiments, four depths, four sediment mixtures, and three time sequences, which resulted in a total of 144 data points per chemical parameter. The surface water was similarly averaged over three replicate experiments, four sediment mixtures, and three times, which yielded 36 data points per chemical

Table 4

Chemical Parameters Averaged by Replicate and Time

(Mean ± One Standard Deviation)

Parameter	Surface Water	Pore Water
Oxygen (mg/ℓ)	5.92 ± 0.98	0.34 ± 0.53
pH	7.78 ± 0.13	7.09 ± 0.22
Total ammonia (mg/ℓ)	0.33 ± 0.47	11.28 ± 8.56
Total sulfide (mg/ℓ)	0	0.58 ± 1.61
Eh (mV)	-29 ± 34	-260 ± 41

parameter. The difference between surface and pore waters was obvious. The oxygen values were an order of magnitude lower in the pore waters than in the surface waters. The ammonia values were over an order of magnitude greater in the pore waters than in the surface waters. Sulfide values became rather high in pore waters, while no sulfide was ever detected in the surface waters. In addition, the pH was about 0.7 unit lower in the pore waters, and the Eh readings in the pore waters were on the order of 200 mV more negative than those in the surface waters. In summary, the surface water environment appeared to be much more conducive to the survival of benthic organisms than the environment which exists within the sediment.

67. It was not possible, however, to deduce from these experiments whether chemical conditions acted in any way as stimuli, or if they did, what the exact chemical stimuli were or the critical concentration which must be reached before one of the parameters became a stimulus for migration. Considerable variation was found among replicate experiments (Tables A1-A5). The cause for this variability was not precisely known; however, the most probable was that in running experiments which require large volumes of sediment such as those performed in this work, it is almost impossible to obtain sediment material which is exactly the same from one experiment to another. In fact, sediments which were used possessed different initial pore water properties. For example, the muds used in the July and August (1976) experiments were

anoxic before being homogenized and dumped into the aquaria, whereas in the earlier experiments this was not the case. Variation in the data is perhaps indicative of what might result from an actual dredging situation. For instance, if sediment was taken from different areas or during different seasons of the year, it could produce different chemical environmental effects upon the disposal area. Therefore, it would be more realistic to study the interstitial water chemistry of an active disposal area rather than attempt to extrapolate the results of aquarium experiments to the natural environment.

Biology

68. During the course of this project 40 tons of sediment were collected and processed to provide substratum for 481 experiments and 15,174 test animals. Core experiments involved 101 tests and 1,744 test animals, and aquaria experiments involved 383 tests and 13,430 test animals. *Mercenaria mercenaria*, *Scoloplos fragilis*, *Nereis succinea*, and *Parahaustorius longimerus* were the main species and were featured in 120, 128, 82, and 86 experiments with 2,669, 5,530, 1,365, and 3,670 test animals, respectively. *Nucula proxima*, *Ilyanassa obsoleta*, and *Neopanope sayi* were featured in 10, 39, and 19 experiments with 1,016, 672, and 252 test animals, respectively.

Core Burial Experiments

Mercenaria mercenaria

69. In a series of fifteen 2-hour and 24-hour experiments at water temperatures of 22 to 25°C with 1-2 cm, 3-4 cm, 7 cm, and 14-16 cm of sand, there was an increase in the mean vertical distance that animals migrated (vertical migration distance) with increasing depth. The vertical migration distance when covered with 1-2 cm of sand was 0.8-1.6 cm; 3-4 cm of sand resulted in 1.5-2.0 cm of movement; 7 cm of sand gave 2.9 cm; and animals covered with 14-16 cm of sand had a mean vertical migration distance of 3.6-4.2 cm. The mean distance of migration

was highest in the deepest sediment. Some bivalves achieved the surface of the topmost layer. These results indicated that M. mercenaria was able to migrate at least through 16 cm of sand under summer temperatures within a short period of time.

70. In another series of four 1-day and 18-day experiments at water temperatures of 19 to 22°C with three depths of sand (30 cm, 50 cm, and 85cm), there was an increase in percent mortality with time and depth. There was no mortality by Day 1. By Day 4, 11, and 18 mortality averaged over all sediment depths was 17, 78, and 63 percent, respectively, with no mortalities among controls. In terms of sediment depth, percent mortality averaged over all time periods was 31, 40, and 55 percent for 30 cm, 50 cm, and 85 cm, respectively. These results indicated that mortalities could be expected after 11 days among clams covered with more than 30 cm of sand. The terminal depth for M. mercenaria was at least 85 cm as some were able to vertically migrate through all depths by Day 1 with a few bivalves reaching the top in 50 cm by Day 4 and Day 18. The clam that reached the surface of 85 cm by Day 18 eventually perished.

Scoloplos fragilis

71. In a series of nine 2-hr to 1-day experiments at water temperatures ranging from 14 to 21°C in 1 cm and 30 cm of sand, there was a relationship between vertical migration distance and sediment depth for Scoloplos fragilis. There was also some suggestion of the effect of temperature on vertical migration distance. At both temperatures all worms migrated to the surface of the 1-cm overburden. At the higher temperature the mean vertical migration distance was 14 cm when covered with 30 cm of sand, and at the lower temperature was only 11 cm when covered to the same depth. Some S. fragilis were able to migrate to the surface of 85 cm of sand.

72. In another set of seven 4-hr and 1-day experiments at water temperatures of 17 to 18°C in 7 cm and 11 cm of silt-clay, there was a marked relationship between vertical migration distance and sediment depth. Vertical migration distance was 6 cm when covered with 7 cm of silt-clay and 5 cm when covered with 11 cm of mud for 1 day. For

Scoloplos fragilis, the additional 4 cm of silt-clay exerted a considerable influence over its burrowing activity.

Parahaustorius longimerus

73. In a series of eight 2-hr and 1-day experiments at water temperatures of 21 to 25°C in 1 cm, 3 cm, and 7 cm of sand, there was a relationship between vertical migration distance and increased sediment depth for Parahaustorius longimerus. The mean distance of vertical migration was highest in the deepest sediment. These results indicated that P. longimerus was able to migrate through at least 7 cm of sand under summer temperatures within a short period of time.

74. In another set of seven 4-hr and 4-day experiments at temperatures of 15°C in 15 cm and 30 cm of sand, there was a relationship between vertical migration distance, sediment depth and time. Vertical migration distance of P. longimerus was 9 cm when covered with 15 cm of sand, 13 cm for 30 cm overburdens. Again, the migration distance was higher in the greater sediment depth. Vertical migration distance when covered by 30 cm of sand was 29 cm after 4 and 12 hours, 14 cm by Day 1, 10 cm by Day 2, 9 cm by Day 3, and 10 cm by Day 4. These results indicated that after 12 hours in greater than 15 cm of sediment at these temperatures, there was a marked reduction in burrowing activity. However even after four days in 30 cm of sediment, there still was some burrowing activity. The terminal depth of P. longimerus in sand was at least 85 cm.

PART V: RESULTS

Sediment

75. Substratum zero sediment for the aquarium experiments consisted of 20 to 29 percent well-sorted fine to moderately sorted medium sand, with void ratios of 0.50 to 0.75, and total organic and carbon contents of 0.03 to 0.10 percent, respectively.

76. Four combinations of two sediments were used as the simulated dredged material. The coarse-grained material was a very well-sorted fine to medium sand, while the fine-grained sediment was a very poorly sorted silt.

77. The 100 percent sand exhibited no consolidation over the 15-day durations of the various experiments. There was no significant variation in void ratio with depth or for the duration of the experiment at each sampling depth (Table 5). The 100 percent silt-clay material consolidated measurably during each experiment. There were significant decreases in void ratio and water content with depth during all stages of the experiments (Tables 5 and 6). These vertical variations were attributed to consolidation of deep layers due to the weight of the overlying layers of dredged material. A very significant decrease in both void ratio and water content was observed with time (Tables 5 and 6). This consolidation of the silt-clay would cause pore water to be squeezed upward and out of the sediment. The total organic carbon content did not change significantly with depth or time (Table 7). This indicated that the dredged material retained vertical homogeneity when placed in the tanks.

78. In placing the 40 percent/60 percent and 20 percent/80 percent silt-clay/sand combinations, vertical homogeneity could not be maintained. In these cases the sand settled more rapidly, resulting in significant vertical variations in total organic carbon content (Table 7), as well as void ratio (Table 5) and water content (Table 4), except for carbon in the 40 percent silt-clay/60 percent sand material. As was the case with the pure sands and silt-clay, there was no significant change

Table 5

Void Ratio ANOVA Results for 15-Day Experiments

Sediment	Source of Variation	df	SS	F_S
100% Silt-Clay	Subgroups	14	40.242	
	Depth	4	7.390	3.481*
	Time	2	30.655	28.882**
	Depth × Time (interaction)	8	2.197	0.517 n.s.
	Within Subgroups (error)	30	15.921	
	Total	44	56.163	
20% Silt-Clay/ 80% Sand	Subgroups	14	1.924	
	Depth	4	1.703	50.484**
	Time	2	0.049	2.905 n.s.
	Depth × Time (interaction)	8	0.173	2.564*
	Within Subgroups (error)	30	0.253	
	Total	44	2.177	
40% Silt-Clay/ 60% Sand	Subgroups	14	12.788	
	Depth	4	7.783	15.349**
	Time	2	4.310	17.000**
	Depth × Time (interaction)	8	0.695	0.685 n.s.
	Within Subgroups (error)	30	3.803	
	Total	44	16.591	
100% Sand	Subgroups	11	0.324	
	Depth	3	0.065	1.372 n.s.
	Time	2	0.075	2.375 n.s.
	Depth × Time (interaction)	6	0.184	1.942 n.s.
	Within Subgroups (error)	24	0.379	
	Total	35	0.803	

(Sand: using inverse void ratio to obtain normal distribution of data)

* $F_S > F_{(0.05)}$, ** $F_S > F_{(0.01)}$, n.s. = not significant.

Table 6

Water Content ANOVA Results for 15-Day Experiments

Sediment	Source of Variation	df	SS	F_S
100% Silt-Clay	Subgroups	14	84,173.84	
	Depth	4	38,444.50	9.572**
	Time	2	41,387.44	20.609**
	Depth × Time (interaction)	8	4,341.90	0.541 n.s.
	Within Subgroups (error)	30	30,123.50	
	Total	44	114,297.34	
20% Silt-Clay/ 80% Sand	Subgroups	14	10,010.84	
	Depth	4	8,655.91	12.795**
	Time	2	186.27	0.551 n.s.
	Depth × Time (interaction)	8	1,168.66	0.864 n.s.
	Within Subgroups (error)	30	5,073.72	
	Total	44	15,084.56	
40% Silt-Clay/ 60% Sand	Subgroups	14	26,200.51	
	Depth	4	18,855.95	10.407**
	Time	2	5,903.10	6.516**
	Depth × Time (interaction)	8	1,441.46	0.398 n.s.
	Within Subgroups (error)	30	13,589.48	
	Total	44	39,789.99	
100% Sand	Subgroups	11	29.38	
	Depth	3	21.55	3.397*
	Time	2	3.26	0.771 n.s.
	Depth × Time (interaction)	6	4.57	0.361 n.s.
	Within Subgroups (error)	24	50.74	
	Total	35	80.12	

* $F_S > F_{(0.05)}$, ** $F_S > F_{(0.01)}$, n.s. = not significant.

Table 7

Percent Carbon ANOVA Results for 15-Day Experiments

Sediment	Source of Variation	df	SS	F_S
100% Silt-Clay	Subgroups	14	0.350	
	Depth	4	0.130	0.886 n.s.
	Time	2	0.070	0.955 n.s.
	Depth × Time (interaction)	8	0.150	0.511 n.s.
	Within Subgroups (error)	30	1.100	
	Total	44	1.450	
20% Silt-Clay/ 80% Sand	Subgroups	14	0.773	
	Depth	4	0.632	4.566*
	Time	2	0.036	0.520 n.s.
	Depth × Time (interaction)	8	0.104	0.376 n.s.
	Within Subgroups (error)	30	1.038	
	Total	44	1.811	
40% Silt-Clay/ 60% Sand	Subgroups	14	1.613	
	Depth	4	1.065	2.029 n.s.
	Time	2	0.079	0.301 n.s.
	Depth × Time (interaction)	8	0.469	0.447 n.s.
	Within Subgroups (error)	30	3.937	
	Total	44	5.550	
100% Sand	Not normally distributed.			

* $F_S > F_{(0.01)}$, n.s. = not significant.

in percent carbon with time (Table 7). The difference between the two mixtures was revealed by the void ratios and water contents. With the 40/60 mixture, there was a significant decrease in water content and void ratio with time (Tables 5 and 6). Consolidation similar to that exhibited by the pure silt also occurred with this mixture. The 20/80 mixture contained a high enough percentage of sand so that consolidation with time did not occur and the void ratio and water contents did not change significantly.

One- and Eight-Day Burial Experiments (A)

Mercenaria mercenaria

79. Summer temperatures. For summer temperatures in 20 to 32 cm of silt-clay and sand, the mean percent mortality of *Mercenaria mercenaria* ranged from 3 to 13% at the end of Day 1 and from 1 to 43% at the end of Day 8 (Table 8). Mortality increased with time and depth in both sediment types, except for 20 cm of sand. Mortality was lower in sand than in silt-clay by Day 8. Control experiments for the eight-day period showed no mortality in silt-clay or sand for 45 and 94 animals, respectively.

80. The mean percent of organisms that migrated from substratum zero (percent migration) ranged from 69 to 83 percent by Day 1 and from 88 to 96 percent by Day 8. Percent migration increased with time and depth in both sediment types (Table 8). The uppermost layer from which clams were recorded was not always the top layer and, in fact, the maximum distance migrated commonly varied with sediment type, depth, and time. In this case, the highest percent of bivalves that reached the top layer by Day 1 was 22 percent in sand 32 cm deep.

81. Winter temperatures. For winter temperatures in 16 and 32 cm of sand and 32 cm of silt-clay, mortality of *M. mercenaria* ranged from 4 to 15 percent by Day 1 and from 15 to 23 percent by Day 8 (Table 9). There was some increase in mortality with time for both depths of sand. Mortality was lower in sand than in silt-clay by Day 1 but was slightly higher in sand by Day 8. Control experiments for the eight-day period showed 10% mortality from 40 individuals in both silt-clay and sand.

Table 8

One- and Eight-Day Tests of *Mercenaria mercenaria* in Aquaria at Summer Temperatures

Sediment Type	Sampling Layer (cm)**	Day 1*						Day 8*					
		No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %	No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %
51-57% Silt-Clay 24 cm deep†	20-24	2	4	4	0	0	0	0	0	0	0	0	0
	16-20	1	2	7	0	0	0	0	0	0	0	0	0
	12-16	2	4	11	0	0	0	23	50	50	0	0	0
	8-12	8	18	29	0	0	0	2	4	54	1	5	5
	4- 8	9	20	49	0	0	0	9	20	74	9	45	50
	0- 4	9	20	69	0	0	0	9	20	93	8	40	90
	Sub Z	14	31	100	6	100	100	3	7	100	2	10	100
	Total	45			6			46			20		
		Test mortality = 13%						Test mortality = 43%					
		Control mortality = 0%						Control mortality = 0%					
54-55% Silt-Clay 32 cm deep†	28-32							2	4	4	0	0	0
	24-28	1	2	2	0	0	0	4	8	12	1	5	5
	20-24	4	8	10	0	0	0	18	37	49	0	0	5
	16-20	5	10	19	0	0	0	1	2	51	1	5	10
	12-16	5	10	29	0	0	0	2	4	55	2	10	19
	8-12	5	10	38	0	0	0	10	20	76	8	38	57
	4- 8	3	6	44	0	0	0	6	12	88	5	24	81
	0- 4	19	37	81	0	0	0	3	6	94	1	5	86
	Sub Z	10	19	100	2	100	100	3	6	100	3	14	100
	Total	52			2			49			21		
		Test mortality = 4%						Test mortality = 43%					
		Control mortality = 0%						Control mortality = 0%					

* Cum % refers to Cumulative Percent.
** Sub Z refers to Substratum Zero.
† Results based on two replicates.
†† Results based on four replicates.

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Table 8 (Concluded)

Sediment Type	Sampling Layer (cm)**	Day 1*						Day 8*					
		No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %	No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %
Sand 20 cm deep††	16-20	12	12	12	0	0	0						
	12-16	42	41	53	0	0	0	85	91	91	0	0	0
	8-12	2	2	55	0	0	0	2	2	94	0	0	0
	4- 8	10	10	65	0	0	0	0	0	94	0	0	0
	0- 4	19	19	83	2	67	67	2	2	96	0	0	0
	Sub Z	17	17	100	1	33	100	4	4	100	1	100	100
	Total	102			3			93			1		
		Test mortality = 3% Control mortality = 0%						Test mortality = 1% Control mortality = 0%					
Sand 32 cm deep††	28-32	21	22	22	0	0	0	17	17	17	0	0	0
	24-28	10	10	32	0	0	0	55	56	73	0	0	0
	20-24	5	5	37	0	0	0	4	4	77	0	0	0
	16-20	10	10	47	0	0	0	3	3	80	1	6	6
	12-16	6	6	54	2	20	20	2	2	82	2	12	18
	8-12	5	5	49	0	0	20	1	1	83	0	0	18
	4- 8	10	10	69	0	0	20	0	0	83	0	0	18
	0- 4	7	7	76	1	10	30	5	5	88	3	18	35
	Sub Z	23	24	100	7	70	100	12	12	100	11	65	100
	Total	97			10			99			17		
		Test mortality = 10% Control mortality = 0%						Test mortality = 17% Control mortality = 0%					

Table 9

One- and Eight-Day Tests of *Mercenaria mercenaria* in Aquaria at Winter Temperatures

Sediment Type	Sampling Layer (cm)**	Day 1*						Day 8*					
		No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %	No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %
93-95% Silt-Clay 32 cm deep†	28-32	0	0	0	0	0	0	7	18	18	0	0	0
	24-28	0	0	0	0	0	0	5	13	31	0	0	0
	20-24	0	0	0	0	0	0	3	8	38	0	0	0
	16-20	1	3	3	0	0	0	0	0	38	0	0	0
	12-16	1	3	5	0	0	0	3	8	46	0	0	0
	8-12	0	0	5	0	0	0	4	10	56	0	0	0
	4- 8	1	3	8	0	0	0	2	5	62	0	0	0
	0- 4	12	30	38	6	100	100	8	21	82	5	83	83
	Sub Z	25	63	100	0	0	100	7	18	100	1	17	100
	Total	40			6			39			6		
			Test mortality = 15% Control mortality = 10%						Test mortality = 15% Control mortality = 10%				
Sand 16 cm deep††	12-16	0	0	0	0	0	0	6	30	30	0	0	0
	8-12	2	8	8	0	0	0	1	5	35	0	0	0
	4- 8	3	12	20	0	0	0	0	0	35	0	0	0
	0- 4	6	24	44	1	100	100	4	20	55	1	33	33
	Sub Z	14	56	100	0	0	100	9	45	100	2	67	100
	Total	25			1			20			3		
			Test mortality = 4% Control mortality = 10%						Test mortality = 15% Control mortality = 10%				

* Cum % refers to Cumulative Percent.
** Sub Z refers to Substratum Zero.
† Results based on two replicates.
†† Results based on one replicate.

Table 9 (Continued)

Sediment Type	Sampling Layer (cm)**	Day 1*						Day 8*					
		No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %	No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %
Sand 32 cm deep†	28-32	0	0	0	0	0	0	4	10	10	0	0	0
	24-28	0	0	0	0	0	0	1	3	13	0	0	0
	20-24	0	0	0	0	0	0	0	0	13	0	0	0
	16-20	0	0	0	0	0	0	0	0	13	0	0	0
	12-16	1	3	3	0	0	0	1	3	15	0	0	0
	8-12	0	0	3	0	0	0	2	5	20	0	0	0
	4- 8	2	5	8	0	0	0	8	20	40	4	44	44
	0- 4	15	38	45	1	25	25	18	45	85	5	56	100
	Sub Z	22	55	100	3	75	100	6	15	100	0	0	100
	Total	40			4			40			9		
			Test mortality = 10%						Test mortality = 23%				
			Control mortality = 10%						Control mortality = 10%				

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82. Percent migration ranged from 38 to 45% by Day 1 and 55 to 85% by Day 8. Percent migration increased with time for both sediment types and depths. No bivalves reached the top layer of any sediments by Day 1, whereas 10 and 18% moved up through 28-32 cm of sand and silt-clay, respectively, and 30% migrated through 12-16 cm sand (Table 9).

83. For both temperature conditions there was generally an increase in mortality with time. There was also an indication of increased mortality with depth over time for both temperature conditions. Percent migration also increased over time for summer and winter temperatures. However, percent migration was generally higher under summer temperatures than winter ones (Tables 8 and 9). This was particularly marked by the end of Day 1.

Nucula proxima

84. For summer temperatures in 8, 16, and 32 cm of silt-clay, mortality of Nucula proxima ranged from 0 to 21% by Day 1 and from 41 to 80% by Day 8 (Table 10). Mortality increased greatly with time at all depths. Mortality was lower in shallow silt-clay (0-8 cm) over time than in the other two depths. Control experiments for the eight-day period showed no mortality for 200 individuals.

85. Percent migration ranged from 32 to 95% by Day 1 and from 56 to 100% by Day 8. Percent migration decreased with time in 16 cm of silt-clay, but increased slightly in 8 cm of silt-clay and considerably more in 32 cm of silt-clay (Table 10). More bivalves reached the top layer in 8 cm of silt-clay than in the other two depths by Day 1 and Day 8. No experiments were conducted with N. proxima under winter conditions.

Ilyanassa obsoleta

86. For summer temperatures in 24 and 32 cm of silt-clay and 20 and 32 cm of sand, mortality ranged from 4 to 21% by Day 1 and from 36 to 81% by Day (Table 11). Mortality increased with time in each sediment type and depth. Mortality was lower in silt-clay than sand by Day 8 and increased from 20 cm of sand to 32 cm of sand for the same period. Control experiments for the eight-day period showed no mortality for 200 animals.

Table 10

One- and Eight-Day Tests of *Nucula proxima* in Aquaria at Summer Temperatures

Sediment Type	Sampling Layer (cm)**	Day 1*						Day 8*					
		No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %	No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %
53-54% Silt-Clay 8 cm deep†	4- 8	90	90	90	0	0	0	96	81	81	26	54	54
	0- 4	5	5	95	0	0	0	22	19	100	22	46	100
	Sub Z	5	5	100	5	100	100	0	0	100	0	0	100
	Total	100			5			118			48		
		Test mortality = 5% Control mortality = 0%						Test mortality = 41% Control mortality = 0%					
51-56% Silt-Clay 16 cm deep	12-16	63	32	32	0	0	0	1	1	1	1	1	1
	8-12	10	5	37	0	0	0	61	31	31	15	14	15
	4- 8	11	6	42	0	0	0	10	5	36	5	5	20
	0- 4	57	29	71	1	2	2	39	20	56	22	21	41
	Sub Z	57	29	100	40	98	100	89	45	100	63	59	100
	Total	198			41			200			106		
		Test mortality = 21% Control mortality = 0%						Test mortality = 53% Control mortality = 0%					

* Cum % refers to Cumulative Percent.
** Sub Z refers to Substratum Zero.
† Results based on one replicate.
†† Results based on two replicates.

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Table 10 (Concluded)

Sediment Type	Sampling Layer (cm)**	Day 1*						Day 8*					
		No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %	No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %
51-52% Silt-Clay 32 cm deep††	28-32	0	0	0	0	0	0	0	0	0	0	0	0
	24-28	0	0	0	0	0	0	0	0	0	0	0	0
	20-24	2	2	2	0	0	0	0	0	0	0	0	0
	16-20	2	2	4	0	0	0	1	1	1	1	1	1
	12-16	0	0	4	0	0	0	0	0	1	0	0	1
	8-12	2	2	6	0	0	0	4	4	5	1	1	3
	4- 8	2	2	8	0	0	0	11	11	16	8	10	13
	0- 4	24	24	32	0	0	0	42	42	58	28	35	48
	Sub Z	68	68	100	0	0	0	100	42	100	42	53	100
	Total	100			0			100			80		
		Test mortality = 0%						Test mortality = 80%					
		Control mortality = 0%						Control mortality = 0%					

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Table 11

One- and Eight-Day Tests of *Ilyanassa obsoleta* in Aquaria at Summer Temperatures

Sediment Type	Sampling Layer (cm)**	Day 1*						Day 8*					
		No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %	No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %
48-57% Silt-Clay 24 cm deep†	20-24	6	25	25	0	0	0	0	0	0	0	0	0
	16-20	1	4	29	0	0	0	0	0	0	0	0	0
	12-16	3	13	42	0	0	0	16	62	62	0	0	0
	8-12	3	13	54	0	0	0	2	8	69	2	20	20
	4- 8	3	13	67	0	0	0	2	8	77	2	20	40
	0- 4	3	13	79	0	0	0	4	15	92	4	40	80
	Sub Z	5	21	100	5	100	100	2	8	100	2	20	100
	Total	24			5			26			10		
		Test mortality = 21% Control mortality = 0%						Test mortality = 38% Control mortality = 0%					
54-55% Silt-Clay 32 cm deep†	28-32	0	0	0	0	0	0	0	0	0	0	0	0
	24-28	6	25	25	0	0	0	0	0	0	0	0	0
	20-24	8	33	58	0	0	0	10	36	36	1	10	10
	16-20	0	0	58	0	0	0	1	4	39	1	10	20
	12-16	1	4	63	0	0	0	3	11	50	2	20	40
	8-12	0	0	63	0	0	0	0	0	50	0	0	40
	4- 8	6	25	88	3	100	100	0	0	50	0	0	40
	0- 4	3	13	100	0	0	100	8	29	79	0	0	40
	Sub Z	0	0	100	0	0	100	6	21	100	6	60	100
	Total	24			3			28			10		
		Test mortality = 13% Control mortality = 0%						Test mortality = 36% Control mortality = 0%					

* Cum % refers to Cumulative Percent.
** Sub Z refers to Substratum Zero.
† Results based on two replicates.
†† Results based on four replicates.

Table 11 (Concluded)

Sediment Type	Sampling Layer (cm)**	Day 1*						Day 8*					
		No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %	No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %
Sand 20 cm deep††	16-20	2	4	4	0	0	0	0	0	0	0	0	0
	12-16	10	21	25	0	0	0	5	10	10	0	0	0
	8-12	2	4	29	0	0	0	5	10	20	4	13	13
	4- 8	12	25	54	0	0	0	6	12	32	6	19	32
	0- 4	14	29	83	0	0	0	26	52	84	19	61	94
	Sub Z	8	17	100	2	100	100	8	16	100	2	6	100
	Total	48			2			50			31		
			Test mortality = 4% Control mortality = 0%						Test mortality = 62% Control mortality = 0%				
Sand 32 cm deep††	28-32	0	0	0	0	0	0	1	2	2	1	3	3
	24-28	3	6	6	0	0	0	1	2	4	0	0	0
	20-24	0	0	6	0	0	0	2	4	8	1	3	6
	16-20	1	2	8	0	0	0	1	2	10	1	3	9
	12-16	6	12	20	0	0	0	2	4	14	0	0	9
	8-12	6	12	32	0	0	0	7	15	29	5	13	22
	4- 8	10	20	52	0	0	0	12	25	54	10	25	47
	0- 4	16	31	83	1	25	25	15	31	85	15	38	85
	Sub Z	9	18	100	3	75	100	7	15	100	6	15	100
	Total	51			4			48			39		
			Test mortality = 8% Control mortality = 0%						Test mortality = 81% Control mortality = 0%				

87. Percent migration ranged from 79 to 100 percent by Day 1 and from 79 to 92 percent by Day 8. More individuals reached upper layers in silt-clay than in sand by Day 1 and Day 8. No experiments were conducted with *I. obsoleta* under winter conditions.

Scoloplos fragilis

88. Summer temperatures. For summer temperatures in 8 and 16 cm of silt-clay and 20 and 32 cm of sand, mortality ranged from 5 to 90 percent by Day 1 and from 5 to 100 percent by Day 8 (Table 12). Mortality increased with time primarily in silt-clay. Mortality was markedly higher in silt-clay than in sand. Control experiments showed no mortality by Day 8 for silt-clay and sand for 53 and 315 animals apiece.

89. Percent migration ranged from 8 to 90 percent by Day 1 and from 0 to 95 percent by Day 8. By Day 8 there was no migration in silt-clay. The ability of test organisms to achieve upper layers was limited even in 8 cm of silt-clay and 16-20 cm of sand on Day 1.

90. Winter temperatures. For winter temperatures in 16 and 36 cm of sand and 32 cm of silt-clay, mortality of *Scoloplos fragilis* ranged from 5 to 29 percent by Day 1 and from 9 to 45 percent by Day 8 (Table 13). Mortality increased with time in 36 cm of sand and 32 cm of silt-clay. By Day 8 mortality was considerably higher in silt-clay than sand and was higher in 36 cm of sand than in 16 cm of sand. Control experiments for the eight-day period showed mortalities of 7.5 percent of 80 organisms and 3.3 percent of 180 organisms for silt-clay and sand, respectively.

91. Percent migration ranged from 10 to 73 percent by Day 1 and from 2 to 86 percent by Day 8 (Table 13). Percent migration increased with time only in sand. By Day 8 percent migration was generally similar in both depths of sand. No polychaetes reached the top layer by Day 1, and only polychaetes in 16 cm of sand reached the surface in appreciable numbers by Day 8.

92. For both temperature conditions, there was generally an increase in mortality with time with some exceptions. Mortality was considerably higher in silt-clay under summer temperatures than winter temperatures for Day 1 and Day 8 (Tables 12 and 13). Mortality was

Table 12

One- and Eight-Day Tests of *Scoloplos fragilis* in Aquaria at Summer Temperatures

Sediment Type	Sampling Layer (cm)**	Day 1*						Day 8*					
		No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %	No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %
53% Silt-Clay 8 cm deep†	4- 8	4	8	8	0	0	0	0	0	0	0	0	0
	0- 4	1	2	10	0	0	0	0	0	0	0	0	0
	Sub Z	45	90	100	45	100	100	50	100	100	50	100	100
	Total	50			45			50			50		
		Test mortality = 90% Control mortality = 0%						Test mortality = 100% Control mortality = 0%					
56% Silt-Clay 16 cm deep†	12-16	1	2	2	0	0	0	0	0	0	0	0	0
	8-12	2	4	6	0	0	0	0	0	0	0	0	0
	4- 8	1	2	8	0	0	0	0	0	0	0	0	0
	0- 4	0	0	8	0	0	0	0	0	0	0	0	0
	Sub Z	46	92	100	21	100	100	50	100	100	50	100	100
	Total	50			21			50			50		
		Test mortality = 42% Control mortality = 0%						Test mortality = 100% Control mortality = 0%					

* Cum % refers to Cumulative Percent.
** Sub Z refers to Substratum Zero.
† Results based on one replicate.
†† Results based on four replicates.

Table 12 (Concluded)

Sediment Type	Sampling Layer (cm)**	Day 1*						Day 8*					
		No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %	No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %
Sand 20 cm deep††	16-20	3	1	1	0	0	0	0	0	0	0	0	0
	12-16	38	12	13	0	0	0	70	19	19	0	0	0
	8-12	45	15	28	0	0	0	101	27	46	0	0	0
	4- 8	97	32	60	0	0	0	107	29	76	0	0	0
	0- 4	93	30	90	0	0	0	70	19	95	0	0	0
	Sub Z	29	10	100	28	100	100	20	5	100	20	100	100
	Total	305			28			368			20		
		Test mortality = 9% Control mortality = 0%						Test mortality = 5% Control mortality = 0%					
Sand 32 cm deep††	28-32	15	5	5	0	0	0	17	4	4	0	0	0
	24-28	52	17	21	0	0	0	107	26	30	0	0	0
	20-24	51	16	38	0	0	0	73	18	48	0	0	0
	16-20	27	9	46	0	0	0	50	12	60	1	2	2
	12-16	32	10	57	0	0	0	44	11	70	0	0	2
	8-12	39	12	69	0	0	0	35	8	79	0	0	2
	4- 8	26	8	77	0	0	0	24	6	85	0	0	2
	0- 4	20	6	84	0	0	0	12	3	88	0	0	2
	Sub Z	51	16	100	17	100	100	51	12	100	51	98	100
	Total	313			17			413			52		
		Test mortality = 5% Control mortality = 0%						Test mortality = 13% Control mortality = 0%					

Table 13

One- and Eight-Day Tests of *Scoloplos fragilis* in Aquaria at Winter Temperatures

Sediment Type	Sampling Layer (cm)**	Day 1*						Day 8*					
		No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %	No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %
93-95% Silt-Clay 32 cm deep†	28-32	0	0	0	0	0	0	1	1	1	0	0	0
	24-28	2	5	5	0	0	0	0	0	1	0	0	0
	20-24	3	8	13	0	0	0	0	0	1	0	0	0
	16-20	0	0	13	0	0	0	0	0	1	0	0	0
	12-16	3	8	20	0	0	0	1	1	2	0	0	0
	8-12	3	8	28	0	0	0	0	0	2	0	0	0
	4- 8	4	10	38	0	0	0	0	0	2	0	0	0
	0- 4	14	35	73	0	0	0	0	0	2	0	0	0
	Sub Z	11	28	100	8	100	100	83	98	100	38	100	100
	Total	40			8			85			38		
		Test mortality = 20% Control mortality = 7%						Test mortality = 45% Control mortality = 7%					
Sand 16 cm deep†	12-16	0	0	0	0	0	0	21	21	21	0	0	0
	8-12	0	0	0	0	0	0	36	36	57	0	0	0
	4- 8	3	3	3	0	0	0	21	21	78	0	0	0
	0- 4	7	7	10	0	0	0	8	8	86	0	0	0
	Sub Z	90	90	100	29	100	100	14	14	100	9	100	100
	Total	100			29			100			9		
		Test mortality = 29% Control mortality = 3%						Test mortality = 9% Control mortality = 3%					

* Cum % refers to Cumulative Percent.
** Sub Z refers to Substratum Zero.
† Day 1 results based on one replicate, Day 8 results based on two replicates.
†† Results based on three replicates.

Table 13 (Concluded)

Sediment Type	Sampling Layer (cm)**	Day 1* No. of Animals	Day 1* % of Total	Day 1* Cum %	Day 1* Dead Animals	Day 1* % of Total	Day 1* Cum %	Day 8* No. of Animals	Day 8* % of Total	Day 8* Cum %	Day 8* Dead Animals	Day 8* % of Total	Day 8* Cum %
Sand	32-36	0	0	0	0	0	0	2	1	1	0	0	0
36 cm deep††	28-32	3	1	1	0	0	0	14	8	9	0	0	0
	24-28	2	1	2	0	0	0	9	5	14	0	0	0
	20-24	2	1	3	0	0	0	14	8	22	0	0	0
	16-20	2	1	4	0	0	0	16	9	31	0	0	0
	12-16	2	1	5	0	0	0	12	7	37	0	0	0
	8-12	22	9	14	0	0	0	22	12	49	0	0	0
	4- 8	14	6	20	0	0	0	25	14	63	0	0	0
	0- 4	72	31	51	0	0	0	28	16	79	0	0	0
	Sub Z	114	49	100	11	100	100	38	21	100	31	100	100
	Total	233			11			180			31		
		Test mortality = 5%						Test mortality = 17%					
		Control mortality = 3%						Control mortality = 3%					

slightly higher in the sand under winter temperatures than summer temperatures for the same periods.

93. Percent migration was generally higher in sand than silt-clay for both temperatures with the exception of 32 cm of silt-clay for Day 1 under winter temperatures. Percent migration in sand was usually higher in summer than winter, particularly by Day 1. Percent migration in silt-clay was usually higher in winter than summer, particularly by Day 1. In general, relatively few individuals reached the topmost layers in sand or silt-clay for both temperatures except for 16 cm of sand under winter temperatures.

Nereis succinea

94. Summer temperatures. For summer temperatures in 24 and 28 cm of silt-clay, mortality of *Nereis succinea* ranged from 2 to 12% by Day 1 and from 12 to 15% by Day 8 (Table 14). There were no consistent trends relating mortality and time or depth. For example, mortality was lowest in 28 cm of silt-clay by Day 1 and lowest in 24 cm of silt-clay by Day 8. Control experiments for the eight-day period showed no mortality for 41 organisms.

95. Percent migration ranged from 88 to 98% by Day 1 and from 85 to 88% by Day 8. Mean percent migration was generally similar per time and depth. Polychaetes were found in the topmost layer on Day 1, but not on Day 8.

96. Winter temperatures. For winter temperatures in 32 cm of silt-clay and 36 cm of sand, mortality of *N. succinea* ranged from 0 to 15% by Day 1 and from 16 to 35% by Day 8 (Table 15). There was a marked increase in mortality with time in sand. Control experiments for the eight-day period showed no mortality for 20 organisms in sand or silt-clay.

97. Percent migration ranged from 60 to 63% by Day 1 and from 60 to 84% by Day 8 (Table 15). Percent migration increased appreciably with time only in silt-clay. There was an increase in the number of test organisms attaining the topmost layers with time. This was more marked in silt-clay than in sand.

98. In silt-clay there was a suggestion of an increase in

Table 14

One- and Eight-Day Tests of *Nereis succinea* in Aquaria at Summer Temperatures

Sediment Type	Sampling Layer (cm)**	Day 1*						Day 8*					
		No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %	No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %
55% Silt-Clay 24 cm deep†	20-24	6	14	14	0	0	0	0	0	0	0	0	0
	16-20	4	9	23	0	0	0	0	0	0	0	0	0
	12-16	8	19	42	0	0	0	6	15	15	0	0	0
	8-12	9	21	63	1	20	20	13	32	46	0	0	0
	4- 8	8	19	81	0	0	20	15	37	83	0	0	0
	0- 4	3	7	88	0	0	20	2	5	88	0	0	0
	Sub Z	5	12	100	4	80	100	5	12	100	5	100	100
	Total	43			5			41			5		
		Test mortality = 12%						Test mortality = 12%					
		Control mortality = 0%						Control mortality = 0%					
55% Silt-Clay 28 cm deep†	24-28	10	24	24	0	0	0	0	0	0	0	0	0
	20-24	4	10	34	0	0	0	7	17	17	0	0	0
	16-20	16	39	73	0	0	0	10	24	41	0	0	0
	12-16	3	7	80	0	0	0	4	10	51	0	0	0
	8-12	2	5	85	0	0	0	8	20	71	0	0	0
	4- 8	4	10	95	0	0	0	5	12	83	0	0	0
	0- 4	1	2	98	0	0	0	1	2	85	0	0	0
	Sub Z	1	2	100	1	100	100	6	15	100	6	100	100
	Total	41			1			41			6		
		Test mortality = 2%						Test mortality = 15%					
		Control mortality = 0%						Control mortality = 0%					

* Cum % refers to Cumulative Percent.
** Sub Z refers to Substratum Zero.
† Results based on two replicates.

Table 15

One- and Eight-Day Tests of *Nereis succinea* in Aquaria at Winter Temperatures

Sediment Type	Sampling Layer (cm)**	Day 1*						Day 8*					
		No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %	No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %
93-95% Silt-Clay 32 cm deep†	28-32	1	5	5	0	0	0	5	20	20	0	0	0
	24-28	1	5	10	0	0	0	5	20	40	0	0	0
	20-24	1	5	15	0	0	0	3	12	52	0	0	0
	16-20	1	5	20	0	0	0	2	8	60	0	0	0
	12-16	0	0	20	0	0	0	1	4	64	0	0	0
	8-12	2	10	30	0	0	0	2	8	72	0	0	0
	4- 8	3	15	45	0	0	0	2	8	80	1	25	25
	0- 4	3	15	60	0	0	0	1	4	84	0	0	25
	Sub Z	8	40	100	3	100	100	4	16	100	3	75	100
	Total	20			3			25			4		
		Test mortality = 15%						Test mortality = 16%					
		Control mortality = 0%						Control mortality = 0%					
Sand 36 cm deep†	32-36	0	0	0	0	0	0	1	5	5	0	0	0
	28-32	6	25	25	0	0	0	4	20	25	0	0	0
	24-28	2	8	33	0	0	0	5	25	50	0	0	0
	20-24	2	8	42	0	0	0	2	10	60	0	0	0
	16-20	1	4	46	0	0	0	0	0	60	0	0	0
	12-16	0	0	46	0	0	0	0	0	60	0	0	0
	8-12	1	4	50	0	0	0	0	0	60	0	0	0
	4- 8	2	8	58	0	0	0	0	0	60	0	0	0
	0- 4	1	4	63	0	0	0	0	0	60	0	0	0
	Sub Z	9	38	100	0	0	0	8	40	100	7	100	100
	Total	24			0			20			7		
		Test mortality = 0%						Test mortality = 0%					
		Control mortality = 0%						Control mortality = 0%					

* Cum % refers to Cumulative Percent.
** Sub Z refers to Substratum Zero.
† Results based on two replicates.

mortality with time under summer temperatures but not winter temperatures (Tables 14 and 15). Percent migration was lower by Day 1 for winter temperatures than the same day for summer temperatures. The number of organisms that achieved the topmost layer was higher in winter temperatures than summer temperatures by Day 8.

Parahaustorius longimerus

99. Summer temperatures. For summer temperatures in 16 and 32 cm of sand, mortality of *Parahaustorius longimerus* ranged from 2 to 6% by Day 1 and from 5 to 7% by Day 8 (Table 16). Data from control experiments were unavailable here.

100. Percent migration was 100% for Day 1 and Day 8 in both depths. The ability of these amphipods to attain the topmost layers was high for all experiments except in 32 cm of sand on Day 8. Here, 78% attained the layer next to the top (24-28 cm).

101. Winter temperature. For winter temperatures in 16 and 36 cm of sand and 32 cm of silt-clay, mortality of *P. longimerus* ranged from 18 to 43% by Day 1 and from 9 to 99% by Day 8 (Table 17). Mortality increased with time only for silt-clay. Mortality was markedly higher in silt-clay than sand for both Day 1 and Day 8. Control experiments for the 8-day period showed 30% mortality of 100 organisms and 24% mortality of 125 organisms in silt-clay and sand, respectively. Mortalities in the control sand experiments exceeded those in test experiments, which makes comparison of mortalities from the sand data questionable.

102. Percent migration increased with time in sand, but not in silt-clay (Table 17). The number of amphipods that attained the topmost layer was markedly higher in sand than silt-clay for both Day 1 and Day 8. There was some indication of increased upward mobility in the sand with shallower depth.

103. In general, mortality in sand did not increase with time under both temperatures. However, mortalities were definitely higher for Day 1 and Day 8 under winter conditions than summer ones.

104. Migration was 100% under summer conditions for both Day 1 and Day 8. Migration was also high under winter temperatures, but not as high as in summer ones (Tables 16 and 17). Moreover, considerably

Table 16

One- and Eight-Day Tests of *Parahaustorius longimerus* in Aquaria at Summer Temperatures

Sediment Type	Sampling Layer (cm)**	Day 1*						Day 8*					
		No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %	No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %
Sand 16 cm deep†	12-16	57	67	67	2	40	40	81	74	74	3	60	60
	8-12	14	16	84	1	20	60	26	24	97	2	40	100
	4- 8	13	15	99	2	40	100	3	3	100	0	0	100
	0- 4	1	1	100	0	0	100	0	0	100	0	0	100
	Sub Z	0	0	100	0	0	100	0	0	100	0	0	100
	Total	85			5			110			5		
		Total mortality = 6% Control data unavailable						Test mortality = 5% Control data unavailable					
Sand 32 cm deep†	28-32	76	51	51	1	33	33	0	0	0	0	0	0
	24-28	30	20	71	0	0	33	101	78	78	2	18	18
	20-24	13	9	79	0	0	33	10	8	85	3	27	45
	16-20	9	6	85	1	33	67	14	11	96	2	18	64
	12-16	7	5	90	0	0	67	5	4	100	4	36	100
	8-12	3	2	92	0	0	67	0	0	100	0	0	100
	4- 8	6	4	96	0	0	67	0	0	100	0	0	100
	0- 4	6	4	100	1	33	100	0	0	100	0	0	100
	Sub Z	0	0	100	0	0	100	0	0	100	0	0	100
	Total	150			3			130			11		
		Test mortality = 2% Control data unavailable						Test mortality = 8% Control data unavailable					

* Cum % refers to Cumulative Percent.
** Sub Z refers to Substratum Zero.
† Results based on one replicate.

Table 17

One- and Eight-Day Tests of Parahaustorius longimerus in Aquaria at Winter Temperatures

Sediment Type	Sampling Layer (cm)**	Day 1*						Day 8*					
		No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %	No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %
93-95% Silt-Clay 32 cm deep†	28-32	0	0	0	0	0	0	1	1	1	0	0	0
	24-28	3	3	3	0	0	0	0	0	1	0	0	0
	20-24	3	3	6	0	0	0	0	0	1	0	0	0
	16-20	5	5	11	0	0	0	0	0	1	0	0	0
	12-16	5	5	16	0	0	0	1	1	2	1	1	1
	8-12	4	4	20	0	0	0	0	0	2	0	0	1
	4- 8	6	6	26	0	0	0	0	0	2	0	0	1
	0- 4	4	4	30	0	0	0	0	0	2	0	0	1
	Sub Z	70	70	100	43	100	100	98	98	100	98	99	100
	Total	100			43			100			99		
			Test mortality = 43% Control mortality = 30%						Test mortality = 99% Control mortality = 30%				
Sand 16 cm deep††	12-16	7	28	28	0	0	0	5	20	20	0	0	0
	8-12	0	0	28	0	0	0	7	28	48	1	20	20
	4- 8	5	20	48	0	0	0	7	28	76	0	0	20
	0- 4	3	12	60	1	14	14	2	8	84	0	0	20
	Sub Z	10	40	100	6	86	100	4	16	100	4	80	100
	Total	25			7			25			5		
			Test mortality = 28% Control mortality = 24%						Test mortality = 20% Control mortality = 24%				

* Cum % refers to Cumulative Percent.
** Sub Z refers to Substratum Zero.
† Results based on two replicates.
†† Results based on one replicate.
‡ Results based on three replicates.

Table 17 (Concluded)

Sediment Type	Sampling Layer (cm)**	Day 1*						Day 8*					
		No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %	No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %
Sand 36 cm deep‡	32-36	0	0	0	0	0	0	17	14	14	0	0	0
	28-32	17	14	14	0	0	0	50	40	54	0	0	0
	24-28	10	8	22	0	0	0	16	13	66	0	0	0
	20-24	5	4	26	0	0	0	15	12	78	0	0	0
	16-20	6	5	30	0	0	0	7	6	84	0	0	0
	12-16	5	4	34	0	0	0	0	0	84	0	0	0
	8-12	6	5	39	0	0	0	4	3	87	0	0	0
	4- 8	25	20	59	0	0	0	2	2	89	0	0	0
	0- 4	16	13	72	0	0	0	1	1	90	0	0	0
	Sub Z	35	28	100	22	100	100	13	10	100	11	100	100
	Total	125			22			125			11		
		Test mortality = 18% Control mortality = 24%						Test mortality = 9% Control mortality = 24%					

Sheet 2 of 2

more amphipods achieved the topmost layer under summer temperatures than under winter temperatures.

Neopanope sayi

105. Summer temperatures. For summer temperatures in 16 and 32 cm of silt-clay and 20 and 32 cm of sand, mortality of Neopanope sayi ranged from 14 to 100% by Day 1 and from 20 to 90% by Day 8 (Table 18). Mortality increased with time in 32 cm of silt-clay and 32 cm of sand, remained the same in 20 cm of sand, and declined in 16 cm of silt-clay. There was a suggestion of increased mortality with increased depth in sand for Day 1 and Day 8. Control experiments showed no mortality for seven and ten organisms in silt-clay and sand, respectively.

106. Percent migration decreased considerably with time except for 16 cm of silt-clay. The number of crabs per sediment type and depth that attained the topmost layer varied considerably. There were more individuals in the topmost layer of sand by Day 1 than by Day 8 (Table 18). The situation was reversed in silt-clay.

107. Winter temperatures. For winter temperatures in 16 and 32 cm of sand, mortality of N. sayi ranged from 0 to 21% by Day 1 and 26 to 50% by Day 8 (Table 19). Mortality increased with time in both depths and was also higher in 32 cm of sand than 16-cm of sand. Control experiments showed no mortality among 24 organisms.

108. Percent migration increased somewhat with time. Fewer crabs migrated in the deep sand than in the shallow sand for both Day 1 and Day 8 (Table 19). The number of crabs that attained the topmost layer was similar in the shallow sand for Day 1 and Day 8 and increased with time in the deep sand.

109. In general, mortality in sand increased with time for both temperatures. There was strong evidence to indicate that mortality increased with depth and time over both temperatures. Mortalities were higher by Day 1 in summer temperatures than in winter ones. The highest mortality was recorded in 32 cm of sand by Day 8 under summer temperatures (Tables 18 and 19).

110. Percent migration was higher by Day 1 under summer temperatures than winter ones, but was considerably lower by Day 8 for summer

Table 18

One- and Eight-Day Tests of Neopanope sayi in Aquaria at Summer Temperatures

Sediment Type	Sampling Layer (cm)**	Day 1*						Day 8*					
		No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %	No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %
51-55% Silt-Clay 16 cm deep†	12-16	0	0	0	0	0	0	4	57	57	0	0	0
	8-12	0	0	0	0	0	0	0	0	57	0	0	0
	4- 8	1	14	14	1	14	14	0	0	57	0	0	0
	0- 4	3	43	57	3	43	57	0	0	57	0	0	0
	Sub Z	3	43	100	3	43	100	3	43	100	3	100	100
	Total	7			7			7			3		
		Test mortality = 100% Control mortality = 0%						Test mortality = 43% Control mortality = 0%					
54-55% Silt-Clay 32 cm deep†	28-32	0	0	0	0	0	0	5	71	71	1	33	33
	24-28	0	0	0	0	0	0	0	0	71	0	0	33
	20-24	6	86	86	0	0	0	0	0	71	0	0	33
	16-20	0	0	86	0	0	0	0	0	71	0	0	33
	12-16	0	0	86	0	0	0	0	0	71	0	0	33
	8-12	0	0	86	0	0	0	0	0	71	0	0	33
	4- 8	0	0	86	0	0	0	0	0	71	0	0	33
	0- 4	1	14	100	1	100	100	0	0	71	0	0	33
	Sub Z	0	0	100	0	0	100	2	29	100	2	67	100
	Total	7			1			7			3		
		Test mortality = 14% Control mortality = 0%						Test mortality = 43% Control mortality = 0%					

* Cum % refers to Cumulative Percent.
** Sub Z refers to Substratum Zero.
† Results based on one replicate.

Table 18 (Concluded)

Sediment Type	Sampling Layer (cm)**	Day 1* No. of Animals	Day 1* % of Total	Day 1* Cum %	Day 1* Dead Animals	Day 1* % of Total	Day 1* Cum %	Day 8* No. of Animals	Day 8* % of Total	Day 8* Cum %	Day 8* Dead Animals	Day 8* % of Total	Day 8* Cum %
Sand 20 cm deep†	16-20	8	80	80	0	0	0	0	0	0	0	0	0
	12-16	0	0	80	0	0	0	7	70	70	0	0	0
	8-12	1	10	90	1	50	50	0	0	70	0	0	0
	4- 8	1	10	100	1	50	100	0	0	70	0	0	0
	0- 4	0	0	100	0	0	100	0	0	70	0	0	0
	Sub Z	0	0	100	0	0	100	3	30	100	2	100	100
	Total	10			2			10			2		
		Test mortality = 20% Control mortality = 0%						Test mortality = 20% Control mortality = 0%					
Sand 32 cm deep†	28-32	0	0	0	0	0	0	0	0	0	0	0	0
	24-28	8	73	73	0	0	0	0	0	0	0	0	0
	20-24	0	0	73	0	0	0	1	10	10	1	11	11
	16-20	0	0	73	0	0	0	0	0	10	0	0	11
	12-16	0	0	73	0	0	0	1	10	20	0	0	11
	8-12	0	0	73	0	0	0	0	0	20	0	0	11
	4- 8	3	27	100	3	100	100	0	0	20	0	0	11
	0- 4	0	0	100	0	0	100	0	0	20	0	0	11
	Sub Z	0	0	100	0	0	100	8	80	100	8	89	100
	Total	11			3			10			9		
		Test mortality = 27% Control mortality = 0%						Test mortality = 90% Control mortality = 0%					

Table 19

One- and Eight-Day Tests of *Neopanope sayi* in Aquaria at Winter Temperatures

Sediment Type	Sampling Layer (cm)**	Day 1*						Day 8*					
		No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %	No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %
Sand 16 cm deep†	12-16	20	83	83	0	0	0	15	79	79	1	20	20
	8-12	0	0	83	0	0	0	1	5	84	1	20	40
	4- 8	1	4	88	0	0	0	0	0	84	0	0	40
	0- 4	0	0	88	0	0	0	3	16	100	3	60	100
	Sub Z	3	13	100	0	0	0	0	0	100	0	0	100
	Total	24			0			19			5		
			Test mortality = 0% Control mortality = 0%						Test mortality = 26% Control mortality = 0%				
Sand 32 cm deep†	28-32	9	38	38	0	0	0	12	50	50	1	8	8
	24-28	0	0	38	0	0	0	1	4	54	0	0	8
	20-24	1	4	42	1	20	20	0	0	54	0	0	8
	16-20	0	0	42	0	0	20	0	0	54	0	0	8
	12-16	0	0	42	0	0	20	0	0	54	0	0	8
	8-12	1	4	46	0	0	20	0	0	54	0	0	8
	4- 8	0	0	46	0	0	20	0	0	54	0	0	8
	0- 4	3	13	58	0	0	20	3	13	67	3	25	33
	Sub Z	10	42	100	4	80	100	8	33	100	8	67	100
	Total	24			5			24			12		
			Test mortality = 21% Control mortality = 0%						Test mortality = 50% Control mortality = 0%				

* Cum % refers to Cumulative Percent.
** Sub Z refers to Substratum Zero.
† Results based on one replicate.

than winter temperatures. The number of crabs that attained the topmost layer was generally higher under winter temperatures than summer ones.

One-, Eight-, and Fifteen-Day Burial Experiments (B)

Mercenaria mercenaria

111. For summer temperatures in four different sediment types, mortality of *Mercenaria mercenaria* ranged from 0 to 2% at the end of Day 1, from 27 to 70% at the end of Day 8, and from 48 to 92% at the end of Day 15 (Table 20). Mortality increased with time in all sediment types. The mortality increase was generally greater between Day 1 and Day 8 than between Day 8 and Day 15. Control experiments for the fifteen-day period showed 4, 3, 3, and 4% mortality for 100% silt-clay, 40% silt-clay/60% sand, 20% silt-clay/80% sand, and 100% sand, respectively.

112. Percent migration ranged from 55 to 80% by Day 1, from 71 to 94% by Day 8, and from 68 to 86% by Day 15. Percent migration generally increased between Day 1 and Day 8 and decreased slightly between Day 8 and Day 15 (Table 20). A greater increase in the number of individuals recorded in upper layers occurred between Day 8 and Day 15 than between Day 1 and Day 8.

Scoloplos fragilis

113. For summer temperatures in four different sediment types, mortality of *Scoloplos fragilis* ranged from 21 to 52% by Day 1, 10 to 72% by Day 8, and from 29 to 98% by Day 15 (Table 21). There was a general increase in mortality with time except for 100% sand. Mortality was generally lower in 100% sand than in other sediment types. The rate of mortality varied considerably with time in the various sediment types. Control experiments for the fifteen-day period showed 10, 13, 13, and 10% mortality for 100% silt-clay, 40% silt-clay/60% sand, 20% silt-clay/80% sand, and 100% sand, respectively.

114. Percent migration ranged from 18 to 29% by Day 1, 13 to 88% by Day 8, and from 4 to 68% by Day 15 (Table 21). There was a general reduction in migration with time except for 100% sand. Higher

Table 20

One-, Eight-, and Fifteen-Day Tests of *Mercenaria mercenaria* in Aquaria at Summer Temperatures

Sediment Type	Sampling Layer (cm)**	Day 1*						Day 8*						Day 15*					
		No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %	No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %	No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %
92-99% Silt-Clay 40 cm deep†	36-40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	32-36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	28-32	0	0	0	0	0	0	11	13	13	1	4	4	18	21	21	1	2	2
	24-28	0	0	0	0	0	0	7	8	21	1	4	8	9	11	32	1	2	4
	20-24	0	0	0	0	0	0	24	27	48	9	38	46	4	5	37	3	8	12
	16-20	0	0	0	0	0	0	3	3	51	2	8	54	2	2	39	2	6	18
	12-16	0	0	0	0	0	0	3	3	54	1	4	58	2	2	41	1	2	20
	8-12	7	8	8	0	0	0	6	7	61	2	8	66	5	6	47	5	12	32
	4- 8	20	24	32	0	0	0	5	6	67	2	8	74	6	7	54	6	15	47
	0- 4	25	30	62	0	0	0	13	15	82	6	26	100	12	14	68	10	24	71
	Sub Z	32	38	100	0	0	0	16	18	100	0	0	100	28	32	100	12	29	100
	Total	84			0			88			24			86			41		
		Test mortality = 0% Control mortality = 4%						Test mortality = 27% Control mortality = 4%						Test mortality = 48% Control mortality = 4%					
35-43% Silt-Clay/ 57-65% Sand 40 cm deep††	36-40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	32-36	2	3	3	0	0	0	8	10	10	1	4	4	0	0	0	0	0	0
	28-32	1	2	5	0	0	0	6	8	18	1	4	8	0	0	0	0	0	0
	24-28	1	2	7	0	0	0	13	16	34	1	4	12	9	14	14	1	2	2
	20-24	1	2	8	0	0	0	4	5	39	3	12	23	1	2	16	0	0	2
	16-20	2	3	11	1	100	100	3	4	43	3	12	35	1	2	17	1	2	4
	12-16	0	0	11	0	0	100	2	3	46	2	8	42	2	3	20	2	4	8
	8-12	7	11	23	0	0	100	2	3	48	1	4	46	2	3	23	2	4	12
	4- 8	18	30	52	0	0	100	4	5	53	2	8	54	4	6	30	4	8	19
	0- 4	17	28	80	0	0	100	32	41	94	11	42	96	36	56	86	34	65	85
	Sub Z	12	20	100	0	0	100	5	6	100	1	4	100	9	14	100	8	15	100
	Total	61			1			79			26			64			52		
		Test mortality = 2% Control mortality = 3%						Test mortality = 33% Control mortality = 3%						Total mortality = 81% Control mortality = 3%					

* Cum % refers to Cumulative Percent.
** Sub Z refers to Substratum Zero.
† Results based on four replicate.
†† Results based on three replicates.

Table 20 (Concluded)

Sediment Type	Sampling Layer (cm)**	Day 1*						Day 8*						Day 15*					
		No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %	No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %	No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %
17-21%	32-36	0	0	0	0	0	0	2	3	3	0	0	0	0	0	0	0	0	0
Silt-Clay/	28-32	0	0	0	0	0	0	4	6	9	2	4	4	0	0	0	0	0	0
79-83%	24-28	0	0	0	0	0	0	1	2	11	1	2	7	0	0	0	0	0	0
Sand	20-24	0	0	0	0	0	0	0	0	11	0	0	7	0	0	0	0	0	0
36 cm deep††	16-20	0	0	0	0	0	0	0	0	11	0	0	7	0	0	0	0	0	0
	12-16	0	0	0	0	0	0	7	11	21	7	15	22	2	3	3	2	4	4
	8-12	1	2	2	0	0	0	7	11	32	7	15	37	1	2	5	1	2	5
	4- 8	8	12	14	0	0	0	14	21	53	14	30	67	10	16	21	10	18	23
	0- 4	27	42	55	0	0	0	12	18	71	6	13	80	32	52	73	31	54	77
	Sub Z	29	45	100	0	0	0	19	29	100	9	20	100	17	27	100	13	23	100
	Total	65			0			66			46			62			57		
			Test mortality = 0% Control mortality = 3%						Test mortality = 70% Control mortality = 3%						Test mortality = 92% Control mortality = 3%				
100%	32-36	0	0	0	0	0	0	0	0	0	0	0	0	5	7	7	0	0	0
Sand	28-32	0	0	0	0	0	0	23	26	26	0	0	0	6	8	15	0	0	0
36 cm deep†	24-28	0	0	0	0	0	0	5	6	32	0	0	0	10	11	26	1	2	2
	20-24	0	0	0	0	0	0	2	2	34	0	0	0	1	1	27	1	2	4
	16-20	2	2	2	0	0	0	0	0	34	0	0	0	3	3	30	1	2	6
	12-16	5	6	8	0	0	0	4	5	39	3	10	10	3	3	33	3	6	12
	8-12	6	7	15	0	0	0	4	5	44	3	10	20	3	3	36	2	4	16
	4- 8	7	8	23	0	0	0	3	3	47	2	8	28	7	8	44	6	13	29
	0- 4	49	56	79	1	100	100	28	32	79	16	55	83	25	28	72	20	42	71
	Sub Z	18	21	100	0	0	100	18	21	100	5	17	100	25	28	100	14	29	100
	Total	87			1			87			29			88			48		
			Test mortality = 1% Control mortality = 4%						Test mortality = 33% Control mortality = 4%						Test mortality = 55% Control mortality = 4%				

Table 21

One-, Eight-, and Fifteen-Day Tests of *Scoloplos fragilis* in Aquaria at Summer Temperatures

Sediment Type	Sampling Layer (cm)**	Day 1*						Day 8*						Day 15*					
		No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %	No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %	No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %
92-99% Silt-Clay 36 cm deep†	32-36	1	0.5	0.5	0	0	0	3	4	4	0	0	0	1	1	1	0	0	0
	28-32	2	1.0	1.5	0	0	0	4	5	9	0	0	0	4	3	4	0	0	0
	24-28	4	3.0	4.5	0	0	0	2	3	11	0	0	0	0	0	4	0	0	0
	20-24	1	0.5	5.0	0	0	0	1	1	13	0	0	0	0	0	4	0	0	0
	16-20	1	0.5	5.5	0	0	0	0	0	13	0	0	0	0	0	4	0	0	0
	12-16	0	0	5.5	0	0	0	0	0	13	0	0	0	0	0	4	0	0	0
	8-12	5	3.0	8.5	0	0	0	0	0	13	0	0	0	0	0	4	0	0	0
	4- 8	1	0.5	9.0	0	0	0	0	0	13	0	0	0	0	0	4	0	0	0
	0- 4	15	9.0	18.0	0	0	0	0	0	13	0	0	0	0	0	4	0	0	0
	Sub Z	130	82.0	100.0	70	100	100	70	88	100	54	100	100	115	96	100	115	100	100
	Total	160			70			80			54			120			115		
			Test mortality = 49% Control mortality = 10%						Test mortality = 68% Control mortality = 10%						Test mortality = 96% Control mortality = 10%				
35-43% Silt-Clay/ 57-65% Sand 40 cm deep††	36-40	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	32-36	0	0	1	0	0	0	4	3	3	0	0	0	0	0	0	0	0	0
	28-32	7	5	6	0	0	0	5	4	6	0	0	0	0	0	0	0	0	0
	24-28	2	2	8	0	0	0	5	4	10	0	0	0	0	0	0	0	0	0
	20-24	2	2	9	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0
	16-20	4	3	12	0	0	0	1	1	11	0	0	0	0	0	0	0	0	0
	12-16	2	2	14	0	0	0	0	0	11	0	0	0	0	0	0	0	0	0
	8-12	1	1	15	0	0	0	2	1	12	1	1	1	0	0	0	0	0	0
	4- 8	3	2	17	0	0	0	1	1	13	0	0	1	0	0	0	0	0	0
	0- 4	13	10	27	0	0	0	14	10	23	1	1	2	0	0	0	0	0	0
	Sub Z	95	73	100	27	100	100	108	77	100	99	98	100	40	100	100	39	100	100
	Total	130			27			140			101			40			39		
			Test mortality = 21% Control mortality = 13%						Test mortality = 72% Control mortality = 13%						Test mortality = 98% Control mortality = 13%				

* Cum % refers to Cumulative Percent.
** Sub Z refers to Substratum Zero.
† Results for Days 1, 8, and 15 based on 4, 2, and 3 replicates, respectively.
†† Results for Days 1, 8, and 15 based on 3, 3, and 1 replicates, respectively.
‡ Results for Days 1, 8, and 15 based on 3, 2, and 2 replicates, respectively.
‡‡ Results based on four replicates.

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Table 21 (Concluded)

Sediment Type	Sampling Layer (cm)**	Day 1*						Day 8*						Day 15*					
		No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %	No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %	No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %
17-21% Silt-Clay/ 79-83% Sand 36 cm deep‡	32-36	1	1	1	0	0	0	3	4	4	0	0	0	1	1	1	0	0	0
	28-32	2	2	3	0	0	0	4	5	9	0	0	0	3	4	5	0	0	0
	24-28	1	1	3	0	0	0	2	3	11	0	0	0	0	0	5	0	0	0
	20-24	1	1	4	0	0	0	1	1	13	0	0	0	0	0	5	0	0	0
	16-20	1	1	5	0	0	0	0	0	13	0	0	0	0	0	5	0	0	0
	12-16	0	0	5	0	0	0	0	0	13	0	0	0	0	0	5	0	0	0
	8-12	2	2	7	0	0	0	0	0	13	0	0	0	0	0	5	0	0	0
	4- 8	1	1	7	0	0	0	0	0	13	0	0	0	0	0	5	0	0	0
	0- 4	14	12	19	0	0	0	0	0	13	0	0	0	0	0	5	0	0	0
	Sub Σ	97	81	100	62	100	100	70	88	100	54	100	100	76	95	100	76	100	100
	Total	120			62			80			54			80			76		
			Test mortality = 52% Control mortality = 13%						Test mortality = 68% Control mortality = 13%						Test mortality = 95% Control mortality = 13%				
100% Sand 36 cm deep‡‡	32-36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	28-32	0	0	0	0	0	0	47	29	29	0	0	0	12	8	8	0	0	0
	24-28	0	0	0	0	0	0	22	14	43	0	0	0	32	21	29	0	0	0
	20-24	4	3	3	0	0	0	32	20	63	0	0	0	16	11	40	0	0	0
	16-20	0	0	3	0	0	0	10	6	69	0	0	0	11	8	48	0	0	0
	12-16	9	5	8	0	0	0	10	6	75	0	0	0	14	9	57	0	0	0
	8-12	1	1	9	0	0	0	10	6	81	0	0	0	6	4	61	0	0	0
	4- 8	6	4	13	0	0	0	6	4	85	0	0	0	6	4	65	0	0	0
	0- 4	26	16	29	0	0	0	5	3	88	0	0	0	5	3	68	0	0	0
	Sub Σ	114	71	100	57	100	100	20	12	100	16	100	100	48	32	100	43	100	100
	Total	160			57			162			16			150			43		
			Test mortality = 36% Control mortality = 10%						Test mortality = 10% Control mortality = 10%						Test mortality = 29% Control mortality = 10%				

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percentages of S. fragilis reached the topmost layer than with either M. mercenaria or N. succinea. Movement to the upper layers occurred earlier with S. fragilis than M. mercenaria.

Nereis succinea

115. For summer temperatures in four different sediment types, mortality of Nereis succinea ranged from 6 to 29 percent by Day 1, from 17 to 58 percent by Day 8, and from 25 to 61 percent by Day 15 (Table 22). In general, there was an increase in mortality with time. The mortality rate was generally higher between Day 1 and Day 8 than between Day 8 and Day 15. Control experiments for the fifteen-day period showed 22, 2, 2, and 22 percent mortality for 100 percent silt-clay, 40 percent silt-clay/60 percent sand, 20 percent silt-clay/80 percent sand, and 100 percent sand, respectively.

116. Percent migration ranged from 31 to 84 percent by Day 1, 64 to 83 percent by Day 8, and from 45 to 75 percent by Day 15. Percent migration generally decreased with time except for 20 percent silt-clay/80 percent sand (Table 22). A few individuals achieved the topmost layers of 100 percent sand and 20 percent silt-clay/80 percent sand. Movement towards the upper layers occurred earlier with N. succinea than with M. mercenaria and was probably more comparable to the other polychaete, S. fragilis.

Parahaustorius longimerus

117. For summer temperatures in four different sediment types, mortality of Parahaustorius longimerus ranged from 11 to 82 percent by Day 1, 5 to 100 percent by Day 8, and from 35 to 99 percent by Day 15 (Table 23). In general, there was an increase in mortality with time. Mortalities were relatively lower in 100 percent sand than in the sand-silt-clay combinations. Control experiments for the fifteen-day period showed 27, 60, 60, and 27 percent mortality for 100 percent silt-clay, 40 percent silt-clay/60 percent sand, 20 percent silt-clay/80 percent sand, and 100 percent sand, respectively. These mortalities were the highest recorded for the control experiments which attests to the relative sensitivity of P. longimerus to these laboratory manipulations.

118. Percent migration ranged from 23 to 83 percent by Day 1,

Table 22

One-, Eight-, and Fifteen-Day Tests of *Nereis succinea* in Aquaria at Summer Temperatures

Sediment Type	Sampling Layer (cm)**	Day 1*						Day 8*						Day 15*					
		No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %	No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %	No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %
92-99%	36-40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Silt-Clay	32-36	3	5	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40 cm deep†	28-32	7	13	18	0	0	0	12	18	18	0	0	0	4	7	7	0	0	0
	24-28	8	15	33	0	0	0	13	19	37	0	0	0	6	11	18	0	0	0
	20-24	2	3	36	0	0	0	4	6	43	0	0	0	8	15	33	0	0	0
	16-20	4	7	43	0	0	0	5	7	50	0	0	0	3	6	39	0	0	0
	12-16	4	7	50	0	0	0	5	7	57	0	0	0	9	16	57	0	0	0
	8-12	7	13	63	0	0	0	3	4	61	0	0	0	4	7	62	0	0	0
	4- 8	3	5	68	0	0	0	3	4	65	0	0	0	3	6	68	0	0	0
	0- 4	9	16	84	0	0	0	6	9	74	0	0	0	4	7	75	0	0	0
	Sub Z	9	16	100	4	100	100	18	26	100	12	100	100	14	25	100	14	100	100
	Total	56			4			69			12			55			14		
			Test mortality = 7%						Test mortality = 17%						Test mortality = 25%				
			Control mortality = 22%						Control mortality = 22%						Control mortality = 22%				
35-43%	36-40	2	5	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Silt-Clay/	32-36	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
57-65%	28-32	8	20	24	3	25	25	3	10	10	3	23	23	7	17	17	2	13	13
Sand	24-28	7	17	41	1	8	33	5	17	27	4	31	54	5	12	29	0	0	13
40 cm deep††	20-24	3	7	49	0	0	33	9	30	57	1	8	62	3	7	36	0	0	13
	16-20	2	5	54	0	0	33	3	10	67	0	0	62	9	21	57	2	13	27
	12-16	3	7	61	3	25	58	1	3	70	0	0	62	5	12	69	0	0	27
	8-12	2	5	66	1	8	67	4	13	83	0	0	62	1	2	71	0	0	27
	4- 8	3	7	73	0	0	67	0	0	83	0	0	62	1	2	74	0	0	27
	0- 4	4	10	83	1	8	75	0	0	83	0	0	62	0	0	74	0	0	27
	Sub Z	7	17	100	3	25	100	5	17	100	5	38	100	11	26	100	11	73	100
	Total	41			12			30			13			42			15		
			Test mortality = 29%						Test mortality = 43%						Test mortality = 36%				
			Control mortality = 2%						Control mortality = 2%						Control mortality = 2%				

* Cum % refers to Cumulative Percent.
** Sub Z refers to Substratum Zero.
† Results based on four replicates.
†† Results for Days 1, 8, and 15 based on 3, 2, and 3 replicates, respectively.

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Table 22 (Concluded)

Sediment Type	Sampling Layer (cm)**	Day 1*						Day 8*						Day 15*					
		No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %	No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %	No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %
17-21% Silt-Clay/ 79-83% Sand 36 cm deep††	32-36	0	0	0	0	0	0	0	0	0	0	0	0	3	4	4	0	0	0
	28-32	4	6	6	2	11	11	8	22	22	6	29	29	4	5	9	0	0	0
	24-28	4	6	12	0	0	11	3	8	31	1	5	33	27	36	45	20	43	43
	20-24	4	6	18	0	0	11	9	25	56	1	5	38	8	11	56	2	4	48
	16-20	3	4	22	0	0	11	2	6	61	0	0	38	1	1	57	0	0	48
	12-16	0	0	22	0	0	11	0	0	61	0	0	38	4	5	63	0	0	48
	8-12	2	3	25	0	0	11	0	0	61	0	0	38	4	5	68	0	0	48
	4- 8	0	0	25	0	0	11	1	3	64	0	0	38	0	0	68	0	0	48
	0- 4	4	6	31	0	0	11	0	0	64	0	0	38	0	0	68	0	0	48
	Sub Z	47	69	100	16	89	100	13	36	100	13	62	100	24	32	100	24	52	100
	Total	68			18			36			21			75			46		
			Test mortality = 26% Control mortality = 2%						Test mortality = 58% Control mortality = 2%						Test mortality = 61% Control mortality = 2%				
100% Sand 36 cm deep†	32-36	4	6	6	0	0	0	0	0	0	0	0	0						
	28-32	17	25	31	0	0	0	24	36	36	0	0	0	2	4	4	0	0	0
	24-28	7	10	41	0	0	0	15	22	58	0	0	0	14	25	29	0	0	0
	20-24	1	1	42	0	0	0	4	6	64	0	0	0	7	12	41	0	0	0
	16-20	2	3	45	0	0	0	2	3	67	0	0	0	0	0	41	0	0	0
	12-16	2	3	48	0	0	0	1	2	69	0	0	0	1	2	43	0	0	0
	8-12	5	7	55	0	0	0	0	0	69	0	0	0	1	2	45	0	0	0
	4- 8	11	16	71	0	0	0	0	0	69	0	0	0	0	0	45	0	0	0
	0- 4	7	10	81	0	0	0	0	0	69	0	0	0	0	0	45	0	0	0
	Sub Z	13	19	100	4	100	100	21	31	100	20	100	100	30	55	100	30	100	100
	Total	69			4			67			20			55			30		
			Test mortality = 6% Control mortality = 22%						Test mortality = 30% Control mortality = 22%						Test mortality = 55% Control mortality = 22%				

Table 23

One-, Eight-, and Fifteen-Day Tests of *Parahaustorius longimerus* in Aquaria at Summer Temperatures

Sediment Type	Sampling Layer (cm)**	Day 1*						Day 8*						Day 15*					
		No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %	No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %	No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %
92-99% Silt-Clay 40 cm deep†	36-40	0	0	0	0	0	0	0	0	0	0	0	0						
	32-36	0	0	0	0	0	0	0	0	0	0	0	0						
	28-32	0	0	0	0	0	0	1	2	2	1	2	2						
	24-28	0	0	0	0	0	0	0	0	2	0	0	2						
	20-24	1	1	1	1	1	1	0	0	2	0	0	2						
	16-20	1	1	2	1	1	2	0	0	2	0	0	2						
	12-16	3	2	4	2	2	4	0	0	2	0	0	2						
	8-12	9	4	8	4	3	7	0	0	2	0	0	2						
	4- 8	38	20	28	29	23	30	0	0	2	0	0	2						
	0- 4	43	22	50	15	12	42	0	0	2	0	0	2						
	Sub Z	95	50	100	71	58	100	49	98	100	49	98	100						
	Total	190			123			50			50								
		Test mortality = 65%						Test mortality = 100%											
		Control mortality = 27%						Control mortality = 27%											
35-43% Silt-Clay/ 57-65% Sand 40 cm deep††	36-40	0	0	0	0	0	0												
	32-36	1	1	1	0	0	0												
	28-32	1	1	1	0	0	0							0	0	0	0	0	0
	24-28	0	0	1	0	0	0							1	1	1	0	0	0
	20-24	1	1	2	0	0	0							1	1	2	1	1	1
	16-20	0	0	2	0	0	0							0	0	2	0	0	1
	12-16	0	0	2	0	0	0							0	0	2	0	0	1
	8-12	1	1	3	1	1	1							0	0	2	0	0	1
	4- 8	7	5	7	7	6	7							0	0	2	0	0	1
	0- 4	29	19	27	15	12	19							0	0	2	0	0	1
	Sub Z	110	73	100	100	81	100							98	98	100	98	99	100
	Total	150			123									100			99		
		Test mortality = 82%												Test mortality = 99%					
		Control mortality = 60%												Control mortality = 60%					

* Cum % refers to Cumulative Percent.
** Sub Z refers to Substratum Zero.
† Results for Days 1 and 8 based on 4 and 1 replicates, respectively.
†† Results for Days 1 and 15 based on 3 and 2 replicates, respectively.
‡ Results for Days 1, 8, and 15 based on 3, 2, and 1 replicates, respectively.
‡‡ Results for Days 1, 8, and 15 based on 4, 3, and 4 replicates, respectively.

Table 23 (Concluded)

Sediment Type	Sampling Layer (cm)**	Day 1*						Day 8*						Day 15*					
		No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %	No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %	No. of Animals	% of Total	Cum %	Dead Animals	% of Total	Cum %
17-21% Silt-Clay/ 79-83% Sand 36 cm deep†	32-36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	28-32	0	0	0	0	0	0	1	1	1	0	0	0	4	8	8	2	4	4
	24-28	1	1	1	0	0	0	5	5	6	0	0	0	0	0	8	0	0	4
	20-24	0	0	1	0	0	0	1	1	7	0	0	0	0	0	8	0	0	4
	16-20	0	0	1	0	0	0	0	0	7	0	0	0	0	0	8	0	0	4
	12-16	0	0	1	0	0	0	0	0	7	0	0	0	0	0	8	0	0	4
	8-12	0	0	1	0	0	0	0	0	7	0	0	0	0	0	8	0	0	4
	4- 8	1	1	1	1	1	1	0	0	7	0	0	0	0	0	8	0	0	4
	0- 4	33	22	23	8	8	9	0	0	7	0	0	0	0	0	8	0	0	4
	Sub Z	115	77	100	95	91	100	93	93	100	93	100	100	46	92	100	46	96	100
	Total	150			104			100			93			50			48		
		Test mortality = 69%						Test mortality = 93%						Test mortality = 96%					
		Control mortality = 60%						Control mortality = 60%						Control mortality = 60%					
100% Sand 36 cm deep††	32-36	6	3	3	0	0	0	0	0	0	0	0	0	27	13	13	0	0	0
	28-32	24	13	16	1	5	5	145	77	77	0	0	0	15	8	21	1	1	1
	24-28	21	11	27	2	9	14	20	11	88	0	0	0	70	34	55	0	0	1
	20-24	15	8	35	0	0	14	10	5	93	0	0	0	13	7	62	0	0	1
	16-20	13	7	42	0	0	14	2	1	94	0	0	0	2	1	63	0	0	1
	12-16	24	13	55	0	0	14	0	0	94	0	0	0	1	1	64	0	0	1
	8-12	20	10	65	c	0	14	1	1	95	0	0	0	1	1	65	0	0	1
	4- 8	20	10	75	0	0	14	0	0	95	0	0	0	0	0	0	0	0	1
	0- 4	15	8	83	0	0	14	0	0	95	0	0	0	1	1	66	1	1	2
	Sub Z	34	17	100	19	86	100	10	5	100	10	100	100	68	34	100	68	98	100
	Total	192			22			188			10			198			70		
		Test mortality = 11%						Test mortality = 5%						Test mortality = 35%					
		Control mortality = 27%						Control mortality = 27%						Control mortality = 27%					

2 to 95 percent by Day 8, and from 2 to 66 percent by Day 15 (Table 23). Migration generally declined with time. The highest migration was recorded in 100 percent sand. In general, relatively few amphipods achieved the topmost layer. There was some indication that more amphipods reached upper layers between Day 8 and Day 15 than between Day 1 and Day 8. This was particularly marked in the 100 percent sand.

PART VI: DISCUSSION

Mercenaria mercenaria

119. *Mercenaria mercenaria* was categorized as a moderately rapid burrower (Stanley 1970). This species has been commonly found in clean or silty sand or sediment with shell debris, which favors the survival of recently set larvae (Wells 1957). In other burial experiments, it was reported that *M. mercenaria* survived well in sediment depths up to 15 cm for periods of 24 hours (Kranz 1972).

120. In the present project with core experiments, juvenile clams started to migrate within four hours under 16 cm of sand at summer temperatures. Some bivalves achieved the surface of the topmost layer. In other core experiments under similar temperature conditions, some bivalves successfully migrated through 30, 50, and 85 cm of sand within one day; a few managed 50 cm in 4 and 18 days; and one clam reached the surface of 85 cm in 18 days. However, the majority of clams did not move more than 20 cm when challenged by 85 cm of sand. When this species was covered by excessive loads of sand, a few individuals migrated vertically, but the majority were unable to exhume themselves. Kranz (1972) found that the escape capacity of the bivalves, *Yoldia limatula* and *Donax variabilis*, was markedly reduced when buried under 41 cm and 21 cm of sand, respectively. Kranz noted that the differential effect of the depth of burial was only readily apparent in sands. He speculated that the greater pressures created by the weight of larger amounts of sediment might prevent the bivalves from opening their shells.

121. In aquaria experiments "A" under summer temperatures, mortality of *M. mercenaria* increased with time and sediment depth except in 20 cm of sand (Table 8). Mortality was higher in silt-clay than sand by Day 8. More individuals reached the top layer of sand than silt-clay by Day 8.

122. In aquaria experiments "B" under summer temperatures, mortality of *M. mercenaria* also increased with time in all sediment types (Table 20). Higher mortalities were recorded in mixtures of silt-clay

and sand than in 100 percent sand by Day 15. A higher number of individuals was recorded in upper layers between Day 8 and Day 15 than between Day 1 and Day 8.

123. In aquaria experiments under winter temperatures, mortalities were lower than in summer temperatures for silt-clay and sand (Table 9). There was no appreciable difference in mortality between silt-clay and sand under winter temperatures. This contrasts with higher mortalities in silt-clay than sand for experiments "A" and "B" under summer temperatures.

124. Although percent migration generally increased over time for both temperature conditions, percent migration was generally higher under summer temperatures than winter ones. This was particularly marked by the end of Day 1. Savage (1976) reported that the optimal burrowing rate of *M. mercenaria* 3.1 to 3.8 cm in shell length was at a temperature range of 21-31°C. Burrowing activity reduced gradually below 21°C and reduced sharply above 31°C. He also showed that there was no seasonal accommodation in burrowing activity with respect to temperature for *M. mercenaria* but that median burrowing times of *Spisula solidissima* collected in the fall were consistently longer than median burrowing times of those collected in the spring at similar temperatures.

Nucula proxima

125. *Nucula proxima* was categorized as a relatively rapid burrower (Stanley 1970). This species is a deposit-feeder which has been commonly found in sediments with a high percent of silt-clay. *Nucula proxima* was reported to have 90 percent success in escaping 50 cm of its native sediment (Kranz 1972). In contrast, 40 cm of fine sand was totally lethal to *N. proxima* according to Kranz. In aquaria experiments "A" under summer temperatures, mortality of *N. proxima* increased with time and depth (Table 10). Mortality was lowest when covered with 8 cm of silt-clay and highest when covered with 32 cm. The terminal depth for *N. proxima* in silt-clay was 24 cm.

Ilyanassa obsoleta

126. *Ilyanassa obsoleta* is a common intertidal gastropod found on fine and silty-sand bottoms. *Ilyanassa* spends considerable time on the surface of sediments, but may burrow diurnally and burrows seasonally for longer periods of time with the onset of decreasing water temperatures. In aquaria experiments "A" under summer temperatures, mortality of *I. obsoleta* increased with time and depth in silt-clay and sand (Table 11). Mortality was lower in silt-clay than sand by Day 8. More individuals reached upper layers in silt-clay than in sand by Day 1. For these experiments, *I. obsoleta* migrated more successfully in silt-clay than sand. This appears to be consistent with its sediment association under natural conditions.

Scoloplos fragilis

127. *Scoloplos fragilis* is a small-size polychaete that is generally found in fine to medium sand with low percent of silt-clay. This polychaete has a distinct prostomium and moderately well-developed parapodia. It produces a mucoid sheath and sand tube and was considered a sedentary species (Hartman 1957).

128. In core experiments at temperatures ranging from 14 to 18°C and 20 to 21°C, there was a relationship between vertical migration distance and sediment depth for *S. fragilis*. A number of polychaetes successfully migrated through 30 cm of sand. In other core experiments in silt-clay at temperatures of 17 to 18°C, there was a suggestion of reduced efficiency of burrowing in finer grained sediment.

129. In aquaria experiments "A" under summer temperatures, mortality increased with time primarily in silt-clay and was markedly higher in silt-clay than in sand (Table 12). The ability of test organisms to migrate to upper layers was limited even in 8 cm of silt-clay by Day 1.

130. In aquaria experiments "B" under summer temperatures there was a general increase in mortality with time except for 100 percent sand (Table 21). Mortality was generally lower in 100 percent sand than

in other sediment types. There was a general reduction in mean percent migration with time except for 100 percent sand.

131. In aquaria experiments "A" under winter temperatures, mortality increased with time in 36 cm of sand and 32 cm of silt-clay (Table 13). Mortality was considerably lower in silt-clay under winter temperatures than summer temperatures and higher in sand under winter temperatures than summer temperatures.

132. Percent migration in sand was usually higher in summer than winter, whereas migration in silt-clay was usually higher in winter than summer, particularly by Day 1 (Tables 12 and 13). *Scoloplos fragilis* migrated more effectively through sand than silt-clay. This seems consistent with its distribution under natural conditions. Even the smallest amount of silt-clay (20%) affected the burrowing ability of this species. There was an indication of the effect of temperature on burrowing. Higher percent migration was associated with summer tempertures. The effect of sediment type on mortality was also influenced by temperatures. There was lower mortality in silt-clay under winter conditions.

Nereis succinea

133. *Nereis succinea* is a large errantiate polychaete with a distinct prostomium and well-developed parapodia. In the field this species has been found 90 cm or more deep in mud and marshy peat banks with channelized contacts to the surface. *Nereis succinea* also occurs in fine sand, but the organisms used in these experiments were found in mud.

134. The terminal depth of *N. succinea* in sand was 85 cm. In aquaria experiments "A" under summer temperatures, there were no consistent trends between mortality and either time or depth (Table 14). In fact, mortalities were generally lower than those of other species in silt-clay. Percent migration was similar per time and depth. This polychaete reached the topmost layer by Day 1, but not by Day 8.

135. In aquaria experiments "B" under summer temperatures, there was an increase in mortality with time (Table 22). Mortality was generally higher in sediment with some mixture of sand than in 100 percent

silt-clay. In contrast to experiments "A," percent migration generally decreased with time except for 20 percent silt-clay/80 percent sand.

136. In aquaria experiments "A" under winter temperatures, mortality increased with time in sand, but not in silt-clay (Table 15). Percent migration was similar except in silt-clay by Day 8. There was an increase in test organisms attaining the topmost layers with time. There was a suggestion of a reduction in mortality in silt-clay with time under winter conditions. Nereis succinea appeared to be more effective in burrowing in silt-clay than in sand.

Parahaustorius longimerus

137. Parahaustorius longimerus is an amphipod almost exclusively found in clean, well-sorted sand. Its morphological characteristics are well adapted to active deep burrowing (Sameoto 1969, Bousfield 1970). Croker (1967) found in laboratory experiments that P. longimerus burrowed deeper into sand than several other species of haustoriid amphipods.

138. In some of the core experiments of this study under summer temperatures, P. longimerus was able to migrate through at least 7 cm of sand within a few hours. At temperatures of 15°C after 12 hours and at depths greater than 15 cm of sand, there was marked reduction in burrowing activity.

139. In aquaria experiments "A" under summer temperatures, mortality of P. longimerus in sand was negligible (Table 16). At all sediment depths and times there was 100 percent migration. Moreover, the ability of these amphipods to attain the topmost layers was generally high.

140. In aquaria experiments "B" under summer temperatures, there was an increase in mortality with time (Table 23). Mortalities were higher where silt-clay was appreciable. Percent migration also generally declined with time.

141. In aquaria experiments "A" under winter temperatures, mortality increased with time only for silt-clay (Table 17). Mortality was markedly higher in silt-clay than in sand. Percent migration

increased with time in sand, but not in silt-clay. Mortalities were definitely higher in sand under winter conditions than under summer ones, but percent migration was higher under summer temperatures (Tables 16 and 17).

142. Burrowing activity for this species was more effective in sand than in silt-clay. Appreciable amounts of silt-clay increased mortality and reduced percent migration. There was some effect on burrowing with time and temperature. Reduced percent migration and increased mortality were associated with winter temperatures in silt-clay.

Neopanope sayi

143. *Neopanope sayi* is a common xanthid crab and a prominent member of oyster bar communities in Delaware Bay. In aquaria experiments "A" under summer temperatures, mortality increased with time in deep silt-clay and deep sand (Table 18). There was a suggestion of increased mortality with increased depth of sand. Percent migration decreased considerably with time except for shallow depths of silt-clay.

144. In aquaria experiments "A" under winter temperatures, mortality increased with time in sand (Table 19). Percent migration increased somewhat with time. Mortalities were higher under summer temperatures than winter ones. In contrast, the number of crabs that attained the topmost layer was generally higher under winter temperatures than summer ones. These crabs were highly mobile at both summer and winter temperatures. If crabs did not migrate immediately, they experienced difficulty. Many crabs that reached the surface of silt-clay eventually died.

Relationship Between the Biota and Chemical Measures

145. The particle size, density, void ratios, etc., were similar in all experiments using 100 percent sand. Conversely, there were significant differences in sediment properties among 100 percent silt-clay, 20% silt-clay/80 percent sand, 40 percent silt-clay/60 percent sand, and 100 percent sand.

146. Although there were some trends among the chemical data, variability between replicates precluded precise definition of different chemical regimes for the sediment types. However, there were considerable differences between pore water in the aquaria and surface water (Tables 3 and 4).

147. Epifanio and Srna (1975) reported that 110-800 ppm or ammonia was acutely toxic to juvenile oysters and clams, while 7.2 ppm was considered sublethally toxic, as evidenced by decreased filtering efficiency at this concentration. By Day 1 in the aquaria "B" experiments ammonia concentrations in the sediment pore water were 6.1 ppm. After one week ammonia levels were sufficiently high in all sediment pore waters to be considered sublethally toxic to the bivalves tested. Mean values for ammonia and sulfide were 14.4 ppm and 0.85 ppm, respectively, at 15 days. It is possible that ammonia could stimulate avoidance migration. Patrick et al. (1968) reported that 90-ppm ammonia was acutely toxic to Physa heterostropha, a fresh-water snail. In general, gastropods were highly tolerant of ammonia.

148. Colby and Smith (1967) reported that 0.27-ppm hydrogen sulfide was acutely toxic to the amphipod, Gammarus pseudolimnaeus. Theede et al. (1969) reviewed the effects of hydrogen sulfide on marine organisms. The resistance of marine invertebrates to both low O_2 and H_2S at 10°C is summarized in Table 24. In general, bivalves were most resistant, followed in decreasing order of resistance by gastropods, polychaetes, and crustaceans. Again, the sulfide tolerances reported in the literature were considerably higher than those recorded in this study after two weeks (0.85 ppm).

149. Because migration was generally initiated before one day and was essentially completed after one week, sediment chemistry in terms of sulfide apparently had little to do with stimulating migration. On the other hand, it is possible that ammonia, together with low dissolved oxygen, could act to stimulate vertical migration.

150. Oxygen deficiency in the sediment pore water occurred almost immediately as Day 1 values averaged 0.86 ppm. After one week, mean values decreased to 0.156 ppm and were 0.035 ppm after two weeks. Since

Table 24

Resistance of Marine Invertebrates to O_2 Deficiency and H_2S at 10°C

(Theede et al. 1969)

Species	50% Mortality (LD_{50}) Observed at Exposure Times (h)	
	O_2 Deficient (0.21 ppm)	O_2 deficient + Addition of 50 mg $Na_2S.9H_2O/1$ (0.67 ppm Sulfide)
Bivalve Mollusca		
Cyprina islandica	1320	800-1000
Mytilus edulis	840	600
Scrobicularia plana	500- 600	400- 450
Mya arenaria	504	408
Gastropoda		
Littorina littorea	365	180
Littorina saxatilis	144	72
Polychaeta		
Nereis diversicolor	120	96
Crustacea		
Carcinus maenas	48	32
Gammarus oceanicus	15	8
Idotea baltica	6	2
Crangon crangon	2	2

oxygen levels in the experiments decreased so rapidly, they could be a stimulus for migration and eventually become a lethal factor at two weeks for the bivalves studied.

151. There is extensive literature on the ability of bivalves to respire anaerobically (Taylor 1976). VonBrand (1946) stated that a variety of species was capable of surviving long periods of low oxygen levels. Assuming aerobic conditions, oxygen consumption and heart rate increased to repay the oxygen debt (Trueman 1967, Brand 1968). Theede et al. (1969) reported the LD_{50} time was essentially longer than three weeks at oxygen levels of 0.21 ppm at 10°C for a variety of bivalves. Savage (1976) reported that M. mercenaria was able to burrow under very low oxygen conditions. Burrowing rates were most rapid at 1.7 ppm dissolved oxygen. However, in two other experiments at 19.5°C, burrowing rates were significantly higher at 5.7 ppm than at 0.85-1.8 ppm.

152. Reish (1970) reported the effects of low dissolved oxygen on four species of polychaetous annelids. The 28-day TL_M was 2.95 ppm for Nereis grubei and 1.5 ppm for Capitella capitata as a single factor. As nitrate and phosphate concentrations increased, the 28-day TL_M values increased to 5.0 ppm and 3.2 ppm for Nereis and Capitella, respectively.

153. Oxygen values in the vertical migration studies decreased to a level where both Nereis succinea and S. fragilis might be seriously stressed within the two-week experimental period, and certainly could be considered lethal in combination with increasing sulfide and ammonia values.

154. Sameoto (1969) reported that P. longimerus showed greater tolerance to low oxygen levels than any other haustoriid species tested. He determined that 0.46 ppm was the 50 percent mean lethal oxygen concentration for P. longimerus. After Day 1, mean oxygen levels in the vertical migration experiments were 0.156 ppm which were below the reported lethal limits for this species.

PART VII: CONCLUSIONS

155. There were two basic patterns of vertical migration or burrowing response in the burial experiments.

- a. The majority of animals migrated from substratum zero and were distributed several ways.
  - (1) Some animals were evenly distributed throughout the layers (*I. obsoleta* in shallow silt-clay, Day 1, Table 11; *P. longimerus* in 100 percent sand, Day 1, Table 23; *N. succinea* in shallow silt-clay, Day 1, Table 14).
  - (2) Some animals occurred in a bell-shaped frequency distribution with its mode at an intermediate sediment layer (*S. fragilis* in shallow sand, Days 1 and 8, Table 12; *N. succinea* in shallow silt-clay, Day 8, Table 14).
  - (3) Some animals occurred in a bell-shaped frequency distribution that was skewed to upper layers (*P. longimerus* in sand for all depths and times, Table 16; *N. succinea* in deep silt-clay, Day 1, Table 14) or skewed to lower layers (*I. obsoleta* in deep sand, Day 8, Table 11; *M. mercenaria* in deep sand, Day 8, Table 9; *S. fragilis* in deep sand, Day 1, Table 13).
  - (4) Some animals occurred in a bimodal frequency distribution (*N. sayi* in deep sand, Days 1 and 8, Table 18; *N. succinea* in 100 percent sand, Day 1, Table 22; *I. obsoleta* in deep silt-clay, Day 1, Table 11).
  - (5) Some animals occurred in a polymodal frequency distribution (*M. mercenaria* in deep sand, Day 1, Table 8).
- b. The majority of animals remained in substratum zero or in the bottommost layers (*S. fragilis* in deep silt-clay, Day 8, Tables 12 and 13; *P. longimerus* in deep silt-clay, Day 8, Table 17; *P. longimerus* in 40 percent silt-clay/60 percent sand, Day 15, Table 23).

156. Based on these experiments, burrowing responses were influenced by sediment type, sediment depth, duration of burial, and temperature.

- a. In general, mortalities increased with increased amounts of exotic sediment, but this response was species specific.

(1) Mortalities of *P. longimerus* and *S. fragilis* increased considerably in high percentages of silt-clay.

(2) Mortalities of *M. mercenaria* were highest in combinations of silt-clay and sand rather than in 100 percent sand or silt-clay.

(3) Mortalities of the mud snail, *I. obsoleta*, increased with an increase in sand.

b. In general, mortalities increased with increased depths of sediment.

(1) Mortalities of *N. proxima* increased markedly from depths of 0-8 cm through 0-16 cm to 0-32 cm of silt-clay.

(2) Mortalities of *M. mercenaria* increased slightly from depths of 0-16 cm to 0-32 cm of sand.

(3) Mortalities of *N. sayi* increased appreciably from depths of 0-16 cm to 0-32 cm of sand.

c. In general, mortalities increased with time or duration of burial. There was evidence for increased mortality with time for all the species tested. In aquaria experiments "B," the 15-day tests, the following trends were recorded.

(1) There was a progressive increase in mortality of *M. mercenaria* and *N. succinea* with time.

(2) There was an increase in mortality of *P. longimerus* with time except for those in 100 percent sand. Moreover, almost 90 percent of mortality in mixtures of silt-clay and sand occurred in the first eight days.

(3) There was a progressive increase in mortality of *S. fragilis* with time except for those in 100 percent sand.

157. Research on the effect of temperature on burrowing activity was cited by Savage (1976). His work indicates that absolute temperature within certain ranges may not be as critical as the time of the year or season. Some species (*Spisula solidissima*) may be capable of seasonal accommodation in burrowing activity with respect to temperature and others (*M. mercenaria*) may not. For *Spisula solidissima*, burrowing times of the fall stock were consistently longer than those of the spring stock. If seasonal accommodation coincides with a given physiological state (food storage, gametogenesis, spawning) of the organism,

this would be an added stress to a species population or species populations confronted with dredging activities.

d. Although there was some association between mortality and temperature, percent migration was relatively more influenced by temperature.

(1) Mortalities of S. fragilis were higher under summer temperatures in silt-clay and higher under winter temperatures in sand. Percent migration was slightly higher under summer temperatures than under winter ones in sand.

(2) Mortalities of P. longimerus were higher under winter temperatures in sand. Percent migration was markedly higher under summer temperatures than under winter ones in sand.

(3) Mortalities of N. succinea were very similar under winter and summer temperatures in silt-clay. Percent migration was higher under summer temperatures than under winter ones in silt-clay.

(4) Mortalities of M. mercenaria were similar under winter and summer temperatures in sand, but were higher in silt-clay by Day 8 under summer temperatures. Percent migration was higher under summer temperatures than under winter ones in silt-clay and sand.

158. In general, the relationship between burrowing activity (percent migration and mortalities) and sediment pore water chemistry was inconclusive. Based on the literature and these experiments, levels of dissolved oxygen and ammonia approached concentration which might have stressed some of the test organisms within a one- to two-week period. Levels of sulfide were probably not harmful to burrowing activity within this same period. We believe that P. longimerus, S. fragilis, and N. succinea were more sensitive to changes in pore water chemistry than M. mercenaria, although these relationships were not satisfactorily documented.

159. It should be emphasized that there was evidence of synergistic effects on burrowing activity throughout these exepriments. The relative weight of one factor over another was not easy to assess. Regardless, differences in burrowing activity were recorded with coincident changes in time, sediment depth, sediment type, and temperature.

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a. In aquaria experiments "B," the effect of sediment type and time on the pattern of vertical migration and mortality of *S. fragilis* can be inferred.

(1) *Scoloplos fragilis* migrated more rapidly by Day 1 in sediment with mixtures of silt-clay than in 100 percent sand.

(2) By Day 8 there was more burrowing activity in upper layers of 100 percent sand than in sediment with mixtures of silt-clay.

(3) By Day 15 burrowing activity had almost ceased in sediment with mixtures of silt-clay, and the frequency distribution was skewed to the upper layers of sediment in 100 percent sand.

b. In aquaria experiments "A," the effect of sediment load and time on mortality of *N. proxima* can be inferred.

(1) By Day 1 mortality was higher in 16 cm of silt-clay than in 8 cm or 32 cm.

(2) By Day 8 there was a progressive increase in mortality from 8 cm of silt-clay, through 16 cm, to 32 cm.

c. In aquaria experiments "A," the effect of temperature, time, and depth on mortality of *N. sayi* can be inferred.

(1) Mortality was lower in shallow sand than in deep sand by Day 1 for both temperature conditions.

(2) Mortality was lower in sand by Day 1 under winter temperatures than under summer ones.

(3) The mortality pattern was basically the same as for (1) and (2) by Day 8 except that mortality was markedly higher in deep sand under summer temperatures than under winter ones.

160. Morphological characteristics, species behavior, and habitat have been suggested in the literature as criteria for predicting burrowing and escape potential abilities of various organisms. The validity of these criteria are probably better documented for bivalves than for most other taxa. Unfortunately, there are relatively little data on similar aspects of burrowing for other common infaunal taxa (polychaetes and crustaceans). The complex synergistic environmental factors regulating the physiological condition of animals differ widely from one area to another. As a result, the authors recommend caution in unqualifiedly using analogous morphological species and habitats to make

predictions until additional studies on many other taxa show there is a general association between certain morphological characteristics and burrowing behavior. Nevertheless, we consider such an approach a viable means to develop a dependable method for prediction.

161. In conclusion, many of the species tested in these experiments showed a surprising ability to vertically migrate and survive remarkably well in relatively thick depths of native and exotic sediments under laboratory conditions. Assuming that in most cases laboratory experiments of this type represent worst-case conditions compared to field conditions, vertical migration may be an important factor in the recovery of benthic communities in dredging and dredged material disposal areas.

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APPENDIX A: CHEMISTRY DATA

Table A1

Oxygen Concentration (mg/ℓ) in Surface and Pore Water

Replicate No.	100% Sand	20% Silt-Clay/ 80% Sand	40% Silt-Clay/ 60% Sand	100% Silt-Clay	Depth (cm)
		1 Day			
1	6.72	6.72	6.72	6.72	
2	6.40	6.72	6.40	6.08	0
3	5.12	4.16	3.84	4.80	
1	2.21	0.99	3.20	1.70	
2	1.22	0.80	1.50	0.90	2
3	0.51	0.51	0.42	0.42	
1	0.61	1.31	0.20	1.31	
2	1.09	0.90	0.51	0.61	12
3	0.42	0.51	0.42	0.42	
1	0.61	0.90	0.70	0.90	
2	2.30	1.31	0.61	0.42	22
3	0.42	0.42	0.30	0.30	
1	1.22	2.02	0.70	0.51	
2	0.99	1.50	0.42	1.09	32
3	0.30	0.30	0.10	0.20	
		1 Week			
1	6.72	6.72	6.72	6.72	
2	6.72	6.40	6.08	6.72	0
3	5.12	4.80	4.48	4.16	
1	0.30	0.51	0.61	0.80	
2	0.30	0.30	0.30	0.51	2
3	0.00	0.00	0.00	0.00	
1	0.20	0.20	0.20	0.90	
2	0.00	0.10	0.10	0.00	12
3	0.00	0.00	0.00	0.00	
1	0.20	0.30	0.20	0.70	
2	0.20	0.10	0.00	0.00	22
3	0.00	0.00	0.00	0.00	
1	0.00	0.00	0.20	0.30	
2	0.00	0.00	0.00	0.00	32
3	0.00	0.00	0.00	0.00	

Table A1 (Concluded)

Replicate No.	100% Sand	20% Silt-Clay/ 80% Sand	40% Silt-Clay/ 60% Sand	100% Silt-Clay	Depth (cm)
		2 Weeks			
1	6.72	6.72	6.72	6.72	
2	6.72	6.72	6.08	6.72	0
3	5.12	4.80	4.16	4.16	
1	0.20	0.42	0.42	0.30	
2	0.00	0.00	0.00	0.10	2
3	0.00	0.00	0.00	0.00	
1	0.00	0.10	0.10	0.10	
2	0.00	0.00	0.00	0.00	12
3	0.00	0.00	0.00	0.00	
1	0.00	0.00	0.00	0.00	
2	0.00	0.00	0.00	0.00	22
3	0.00	0.00	0.00	0.00	
1	0.00	0.00	0.00	0.00	
2	0.00	0.00	0.00	0.00	32
3	0.00	0.00	0.00	0.00	

Table A2

pH in Surface and Pore Water

Replicate No.	100% Sand	20% Silt-Clay/ 80% Sand	40% Silt-Clay/ 60% Sand	100% Silt-Clay	Depth (cm)
			1 Day		
1	7.78	7.46	7.98	7.85	
2	7.87	7.73	7.76	7.83	0
3	7.76	7.38	7.60	7.83	
1	7.20	7.07	6.81	7.01	
2	7.36	7.05	7.17	6.96	2
3	6.65	6.72	6.35	6.56	
1	7.28	7.12	7.10	7.06	
2	7.11	6.99	7.04	6.97	12
3	7.04	6.75	6.70	7.13	
1	7.38	7.08	7.09	7.12	
2	7.26	7.00	7.01	7.08	22
3	7.09	6.69	6.49	7.08	
1	6.97	7.15	6.93	7.06	
2	7,43	7.06	7.01	7.03	32
3	7.14	6.80	6.58	7.31	
			1 Week		
1	7.91	7.85	7.75	7.91	
2	7.82	7.88	8.06	7.83	0
3	7.75	7.56	7.66	7.64	
1	7.48	7.14	7.19	7.18	
2	7.43	7.06	7.07	7.08	2
3	7.07	6.86	6.39	7.09	
1	7.48	7.17	7.18	7.28	
2	7.30	7.00	7.14	7.07	12
3	7.27	6.87	6.74	7.09	
1	7.31	7.16	7.12	7.18	
2	7.01	7.08	7.07	7.08	22
3	7.40	6.84	6.55	7.07	
1	7.28	7.24	7.06	7.06	
2	7.18	7.06	7.08	6.91	32
3	7.37	6.87	6.66	7.25	

Table A2 (Concluded)

Replicate No.	100% Sand	20% Silt-Clay/ 80% Sand	40% Silt-Clay/ 60% Sand	100% Silt-Clay	Depth (cm)
			2 Weeks		
1	7.90	7.71	7.80	7.87	
2	7.84	7.90	7.85	7.74	0
3	7.81	7.70	7.75	7.75	
1	7.40	7.18	7.25	7.28	
2	7.53	7.12	7.10	7.11	2
3	7.25	6.90	6.67	7.14	
1	7.46	7.23	7.19	7.24	
2	7.44	7.05	7.17	7.12	12
3	7.39	6.93	6.84	7.11	
1	7.45	7.19	7.15	7.19	
2	7.26	7.13	7.10	7.10	22
3	7.45	6.83	6.81	7.08	
1	7.33	7.21	7.20	7.21	
2	7.36	7.09	7.14	7.20	32
3	7.41	6.94	6.89	7.27	

Table A3

Ammonia Concentration (mg/ℓ) in Surface and Pore Water

Replicate No.	100% Sand	20% Silt-Clay/ 80% Sand	40% Silt-Clay/ 60% Sand	100% Silt-Clay	Depth (cm)
			1 Day		
1	0.04	2.38	0.19	0.15	
2	0.11	0.17	1.70	0.17	0
3	0.29	0.29	0.26	0.37	
1	0.02	9.35	7.99	2.89	
2	1.22	2.55	11.90	4.08	2
3	2.89	11.05	16.15	6.80	
1	0.03	11.22	7.14	4.76	
2	1.38	5.61	6.80	5.78	12
3	2.72	13.60	14.45	8.50	
1	0.02	9.69	6.63	4.42	
2	1.12	4.76	8.84	5.44	22
3	2.21	12.75	13.60	7.14	
1	1.70	5.61	3.74	1.56	
2	3.74	3.06	3.91	1.56	32
3	7.14	6.80	7.65	9.01	
			1 Week		
1	0.05	0.70	0.11	0.09	
2	0.13	0.12	0.06	0.13	0
3	0.36	0.32	0.26	0.42	
1	0.70	6.46	13.26	12.92	
2	1.87	8.50	6.12	6.63	2
3	1.87	30.60	30.60	6.29	
1	1.31	11.05	15.81	14.62	
2	3.06	14.96	13.43	12.75	12
3	3.91	34.00	30.60	11.56	
1	0.83	13.60	14.62	13.26	
2	1.70	15.81	11.56	11.22	22
3	3.74	28.90	32.30	14.96	
1	6.80	13.26	8.84	11.56	
2	9.52	13.60	9.35	9.86	32
3	4.08	7.14	22.10	17.00	

Table A3 (Concluded)

Replicate No.	100% Sand	20% Silt-Clay/ 80% Sand	40% Silt-Clay/ 60% Sand	100% Silt-Clay	Depth (cm)
		2 Weeks			
1	0.04	0.41	0.22	0.11	
2	0.13	0.17	0.19	0.20	0
3	0.48	0.32	0.27	0.48	
1	0.48	9.01	11.73	14.96	
2	1.87	11.05	10.20	3.57	2
3	2.38	32.30	9.35	2.55	
1	1.87	9.52	20.40	16.83	
2	3.40	22.10	17.00	10.20	12
3	4.25	40.80	20.40	11.73	
1	2.55	13.26	20.40	16.83	
2	3.23	22.10	17.00	10.37	22
3	5.78	30.60	22.10	16.32	
1	10.88	17.00	16.32	17.00	
2	16.49	17.00	17.00	15.81	32
3	5.78	14.45	20.40	18.70	

Table A4

Sulfide Concentration (mg/ℓ) in Surface and Pore Water

Replicate No.	100% Sand	20% Silt-Clay/ 80% Sand	40% Silt-Clay/ 60% Sand	100% Silt-Clay	Depth (cm)
		1 Day			
1	0.00	0.00	0.00	0.00	
2	0.00	0.00	0.00	0.00	0
3	0.00	0.00	0.00	0.00	
1	0.00	0.00	0.00	0.00	
2	0.00	0.00	0.00	0.00	2
3	0.00	0.00	0.00	0.00	
1	0.00	0.00	0.00	0.00	
2	0.00	0.00	0.00	0.00	12
3	0.00	0.00	0.00	0.00	
1	0.00	0.00	0.00	0.00	
2	0.00	0.00	0.00	0.00	22
3	0.00	0.00	0.00	0.00	
1	0.00	0.00	0.00	0.00	
2	0.00	0.00	0.00	0.00	32
3	0.00	0.00	0.00	0.00	
		1 Week			
1	0.00	0.00	0.00	0.00	
2	0.00	0.00	0.00	0.00	0
3	0.00	0.00	0.00	0.00	
1	0.02	0.05	0.00	0.06	
2	0.00	0.10	0.02	0.00	2
3	1.33	0.37	8.16	0.75	
1	0.02	0.05	0.02	0.03	
2	0.00	0.14	0.07	0.04	12
3	1.70	0.41	1.70	1.50	
1	0.37	0.03	0.02	0.13	
2	0.00	0.17	0.07	0.06	22
3	3.74	2.75	2.24	0.54	
1	0.09	0.03	0.02	0.05	
2	0.02	0.07	0.03	0.10	32
3	9.18	1.90	0.34	0.99	

Table A4 (Concluded)

Replicate No.	100% Sand	20% Silt-Clay/ 80% Sand	40% Silt-Clay/ 60% Sand	100% Silt-Clay	Depth (cm)
		2 Weeks			
1	0.00	0.00	0.00	0.00	
2	0.00	0.00	0.00	0.00	0
3	0.00	0.00	0.00	0.00	
1	0.37	0.12	0.00	0.02	
2	0.17	0.14	0.07	0.02	2
3	0.34	0.24	6.46	0.31	
1	0.99	0.11	0.04	0.03	
2	0.31	0.17	0.14	0.05	12
3	0.78	0.14	2.52	2.58	
1	0.41	0.03	0.04	0.03	
2	0.27	0.28	0.14	0.07	22
3	6.46	2.72	2.07	0.75	
1	0.06	0.04	0.05	0.17	
2	0.34	0.11	0.10	0.19	32
3	8.50	0.54	0.75	1.02	

Table A5

Eh (mV) in Surface and Pore Water

Replicate No.	100% Sand	20% Silt-Clay/ 80% Sand	40% Silt-Clay/ 60% Sand	100% Silt-Clay	Depth (cm)
			1 Day		
1	- 30	- 30	- 50	- 30	
2	- 80	+ 20	0	- 80	0
3	- 60	- 90	- 20	- 10	
1	-250	-240	-290	-240	
2	-300	-280	-220	-320	2
3	-240	-350	-240	-260	
1	-270	-240	-300	-250	
2	-320	-270	-190	-340	12
3	-230	-370	-260	-230	
1	-270	-220	-270	-240	
2	-340	-270	-180	-310	22
3	-240	-310	-250	-280	
1	-250	-240	-310	-260	
2	-300	-280	-200	-300	32
3	-250	-320	-270	-250	
			1 Week		
1	- 40	- 50	+ 20	- 30	
2	- 10	- 80	- 60	- 70	0
3	+ 30	- 20	- 10	+ 30	
1	-220	-190	-200	-280	
2	-290	-340	-290	-310	2
3	-180	-230	-230	-200	
1	-250	-200	-190	-260	
2	-320	-310	-310	-300	12
3	-200	-230	-260	-230	
1	-230	-180	-200	-260	
2	-280	-330	-320	-320	22
3	-210	-250	-240	-210	
1	-240	-210	-180	-270	
2	-310	-310	-300	-290	32
3	-170	-260	-220	-240	

Table A5 (Concluded)

Replicate No.	100% Sand	20% Silt-Clay/ 80% Sand	40% Silt-Clay/ 60% Sand	100% Silt-Clay	Depth (cm)
		2 Weeks			
1	- 50	- 30	- 30	- 10	
2	0	- 60	- 80	- 50	0
3	- 10	0	+ 30	- 20	
1	-310	-250	-240	-260	
2	-220	-290	-290	-310	2
3	-250	-220	-210	-220	
1	-330	-230	-250	-230	
2	-270	-300	-270	-300	12
3	-240	-250	-280	-240	
1	-330	-260	-230	-250	
2	-250	-280	-250	-280	22
3	-270	-230	-270	-210	
1	-310	-260	-210	-270	
2	-250	-270	-280	-290	32
3	-270	-240	-240	-220	

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Maurer, Donald L

Vertical migration of benthos in simulated dredged material overburdens; Vol. I: Marine benthos / by D. L. Maurer ... [et al.], University of Delaware, College of Marine Studies, Lewes, Delaware. Vicksburg, Miss. : U. S. Waterways Experiment Station; Springfield, Va. : available from National Technical Information Service, 1978.

97, 11 p. : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; D-78-35, v.1)

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Literature cited: p. 93-97.

1. Animal behavior. 2. Benthos. 3. Distribution patterns. 4. Dredged material. 5. Invertebrates. 6. Marine animals. 7. Marine deposits. 8. Migration. 9. Sediment. 10. Simulation. 11. Waste disposal sites. I. Delaware. University, Newark. College of Marine Studies. II. United States. Army. Corps of Engineers. III. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; D-78-35, v.1.

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